NASA / TM—1999-209073

A User's Guide for the Differential Reduced Ejector / Mixer Analysis "DREA" Program
Version 1.0

Lawrence J. De Chant
Texas A&M University, College Station, Texas

Shari-Beth Nadell
Glenn Research Center, Cleveland, Ohio

April 1999

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the Lead Center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized data bases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA Access Help Desk at (301) 621-0134

- Telephone the NASA Access Help Desk at (301) 621-0390

- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076

NASA/TM—1999-209073

A User's Guide for the Differential Reduced Ejector/Mixer Analysis "DREA" Program

Version 1.0

Lawrence J. De Chant
Texas A&M University, College Station, Texas

Shari-Beth Nadell
Glenn Research Center, Cleveland, Ohio

National Aeronautics and
Space Administration

Glenn Research Center

April 1999

Available from

NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076
Price Code: A03

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22100
Price Code: A03

A USER'S GUIDE FOR THE
DIFFERENTIAL REDUCED EJECTOR/MIXER ANALYSIS "DREA" PROGRAM
Version 1.0

Lawrence J. De Chant
Texas A&M University
College Station, TX 77843*

Shari-Beth Nadell
NASA Glenn Research Center
Cleveland, OH 44135

Abstract

A system of analytical and numerical two-dimensional mixer/ejector nozzle models that require minimal empirical input has been developed and programmed for use in conceptual and preliminary design. This report contains a user's guide describing the operation of the computer code, DREA (Differential Reduced Ejector/mixer Analysis), that contains these mathematical models. This program is currently being adopted by the Propulsion Systems Analysis Office at the NASA Glenn Research Center. A brief summary of the DREA method is provided, followed by detailed descriptions of the program input and output files. Sample cases demonstrating the application of the program are presented.

Introduction

The Differential Reduced Ejector/mixer Analysis (DREA) method was developed to enable conceptual and preliminary design of two-dimensional mixer/ejector nozzles. The DREA analysis computes overall performance characteristics (secondary flow entrainment or pumping, gross thrust coefficient) of the nozzle as well as flowfield characteristics along the mixing duct. The DREA method was designed to have little reliance on empirically based constants. This requirement resulted from the fact that, in conceptual level design of advanced propulsion components, it is rare that a sufficient database would exist that could be used to develop empirical constants. The method therefore relies on a system of analytical and numerical models that represent the physics involved in the mixing and entrainment process, while providing a method that is relatively simple and quick to apply as compared with complex, time-consuming Computational Fluid Dynamics (CFD) programs. This makes the DREA method ideal for use in performing systems analysis and trade studies, as well as conceptual design of mixer/ejector nozzles.

The DREA method has been coded into a FORTRAN program for application purposes. The program is composed of modules that approximate the flow through an ejector nozzle. Figure 1 illustrates the program structure. The user supplies the basic nozzle geometry and initial flow conditions (total pressure, total temperature, Mach number) at the mixing plane, which is where the DREA analysis begins. The program then performs a modified control volume analysis to compute the secondary mass flow rate and performance characteristics of the nozzle. If this is the only information the user is interested in, the program flow can be stopped at this point. Otherwise, the method continues and performs a combined analytical and numerical two-dimensional analysis to compute flowfield properties along the length of the mixing duct. An inverse design loop is not currently implemented, but can be performed manually by the user.

* Current address; Applied Theoretical and Computational Physics Division; MS D-413, Los Alamos National Laboratory, Los Alamos, NM 87545; ldechant@lanl.gov

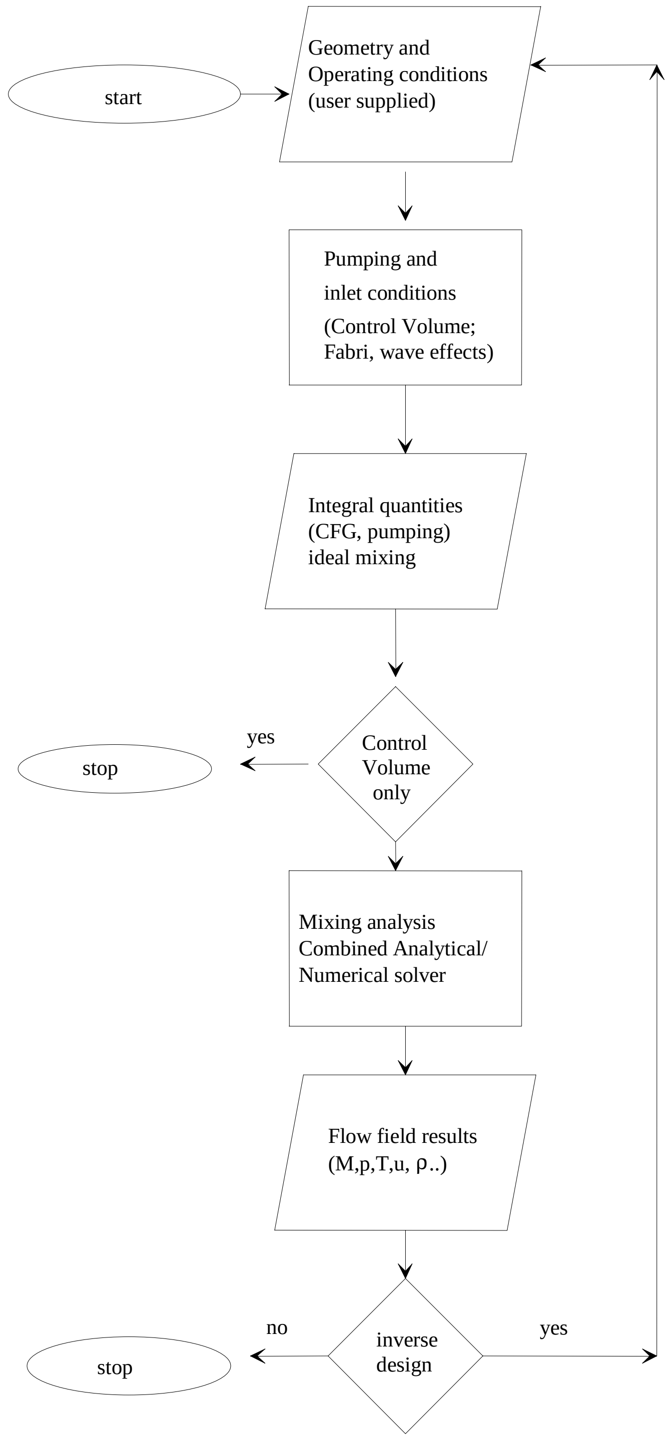


FIGURE 1. Flow chart of the DREA computational method.

DREA includes the option of analyzing an ejector nozzle, where the secondary flow entrainment is not provided as an input but is computed by the method, or a mixer nozzle, where the secondary flow entrainment is specified by the user. In the latter mode, the DREA analysis will compute the performance and flowfield of a nozzle for the given input conditions, regardless of whether or not ejector design constraints, such as back pressure matching for a subsonic ejector, are met. This can be useful when modeling a nozzle in which the secondary flow is somehow pumped into the nozzle, e.g. flow from a bypass fan stream, instead of entrained by the primary flow. DREA also includes a turbulence model (described below), and can analyze the mixing enhancement provided by a vortical chute arrangement as shown in Figure 2.

TWO-DIMENSIONAL MIXER/EJECTOR DESIGN

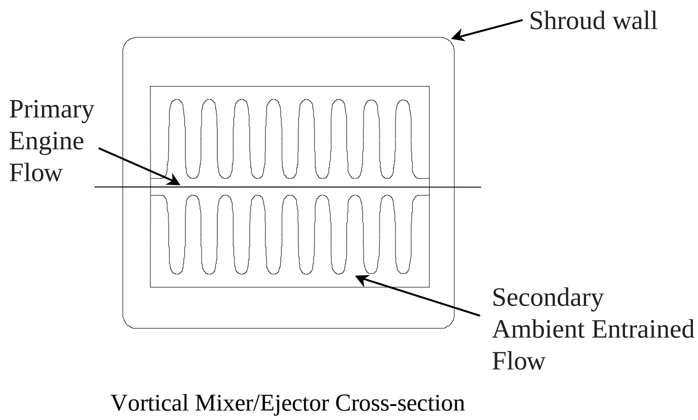


FIGURE 2. Cross section of mixer/ejector nozzle system showing vortical chute system.

Figures 3 and 4 show comparisons of DREA results with test data for both a mixer and an ejector, respectively (ref. 1). Figure 3 includes a comparison of the classical free jet calculation for this mixer. The results clearly indicate the improvement over the classical free jet that the DREA method provides as compared with the model test data. Figure 4 likewise shows good agreement between the DREA analysis and experimental data.

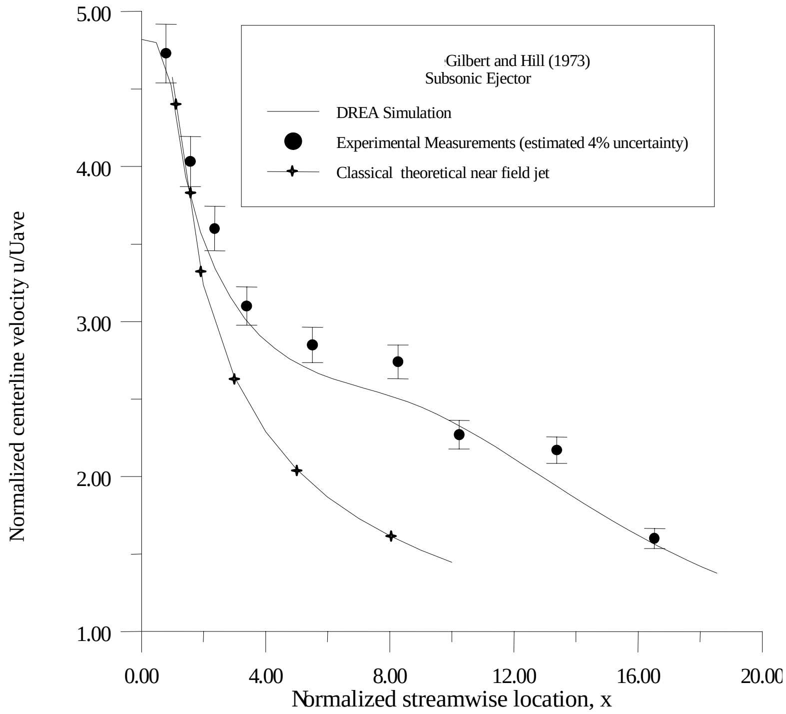


FIGURE 3. A comparison between the DREA simulation and experimental data of Gilbert and Hill (1973) showing centerline velocity versus streamwise location with uncertainties (4%) estimated from the literature.

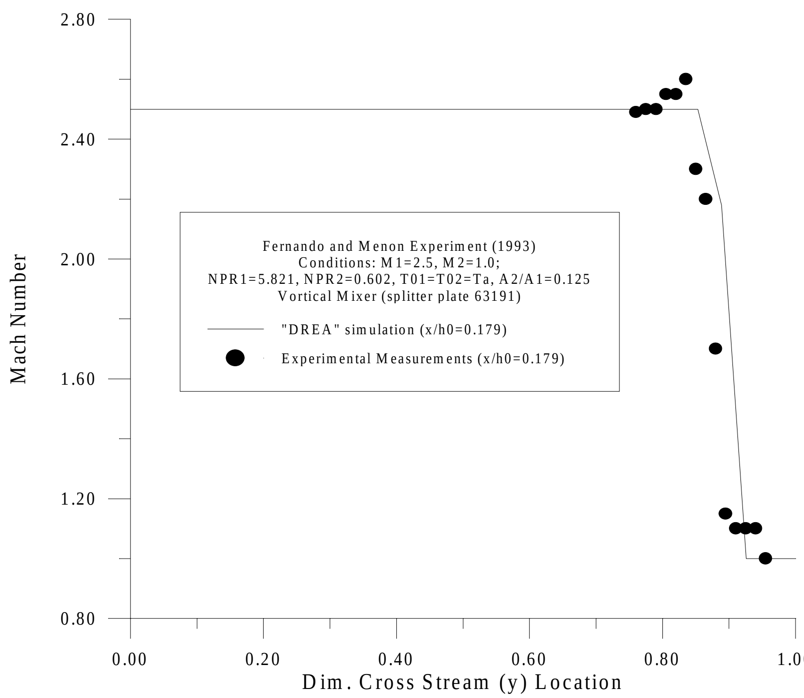


FIGURE 4. A comparison between the DREA simulation and experimental data of Fernando and Menon (1993) showing the Mach number profile for a vortical mixer.

This report is intended to provide the user with the information necessary to set up and run a mixer/ejector nozzle using the DREA program. A brief summary of the DREA method is given, with emphasis on the different nozzle flow regimes (subsonic, supersonic) and the basic mechanics of how an ejector works. This is followed by descriptions of the input parameters required by the DREA program. A brief description of the output files is given. Four example problems are presented. These include more details regarding the information present in the DREA output files.

DREA Method Summary

The information presented in this section will aid the user in understanding the variety of input variables required by the DREA method and how they affect the way the program runs. A detailed technical discussion of the method can be found in reference 1. This section will concentrate upon the variety of flow characteristics in an ejector nozzle. The turbulence model is also briefly described.

Mixer/ejector Flow Characteristics

An ejector is a relatively simple, passive mixing/pumping device that serves to entrain fluid from a secondary stream, mix it with a primary, high energy stream, thus obtaining a mixed (and potentially uniform) exit stream of greater mass flow (Figure 5). The additional mass entrainment is cause by two major effects: (1) inviscid pressure imbalance, which draws fluid into the primary stream from the secondary inlet, and (2) effective viscous components, which drags fluid in from the secondary inlet. These "effective viscous" components are defined as terms which are caused by turbulent mixing effects.

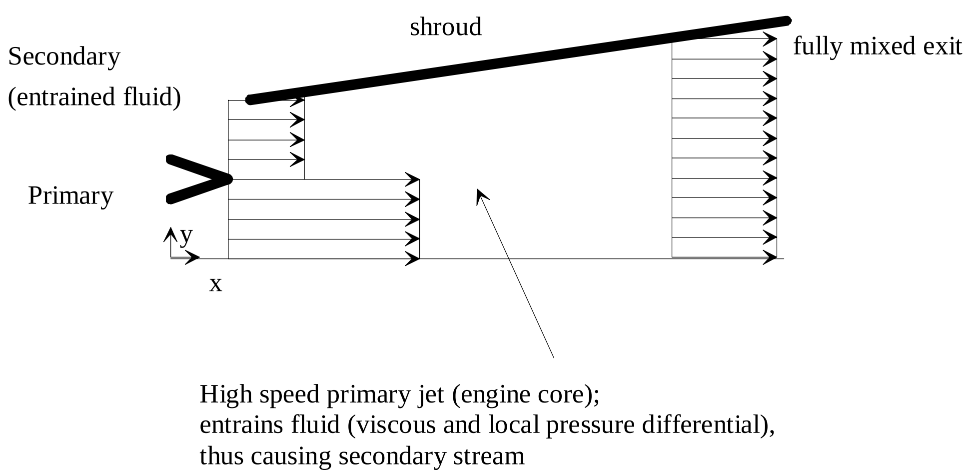


FIGURE 5. Schematic of ejector nozzle operation.

It is necessary to be careful in the description of this process, however, in that through the momentum equation, pressure and effective viscous terms are coupled. Therefore, in reality, the additional mass entrainment is accomplished through a complex process involving both pressure and viscous mechanisms. The turbulent mixing effects are typically estimated using the concept of a turbulent viscosity, but are really strong, non-linear fluctuation type terms and have no relationship to molecular viscosity. Though molecular viscosity is certainly present in any physical flow, the Reynolds number is assumed to be large enough such that molecular viscosity effects are wholly negligible.

Since ejectors involve the mixing of two streams of fluid, which for compressible gas flows may be either supersonic, subsonic, or a combination, several possible flow regimes may exist. These flow regimes are strongly characterized by the extent of supersonic or subsonic flow.

Supersonic flow is properly modeled using a parabolic-hyperbolic equation set. The need for a hyperbolic system stems from the fact that, due to the supersonic nature of the flow, information or disturbances are convected downstream more rapidly than can be transmitted upstream. As one would expect from the mathematical classification (parabolic-hyperbolic), flows of this type are dependent solely on their initial, or upstream, conditions. In contrast, the convective speed of a subsonic flow field is less than the molecular signal propagation velocity, i.e. speed of sound. As such, downstream signals can propagate upstream. For the subsonic flow field, the flow field and even the initial conditions depend upon the downstream conditions. The modeling equations for this case are parabolic-elliptic.

Ultimately simplified equations that have a single character, i.e. parabolic, are developed (ref. 1). This parabolic system is supplemented by initial conditions, which (depending on the flow regime) will respect the potential for downstream dependence. It is apparent that all of the problems of interest will virtually always contain some region of subsonic flow, forcing the inclusion of some form of a downstream constraint.

The first flow that is considered is a supersonic nozzle that has a sufficiently large back pressure (i.e. ambient pressure) to cause the supersonic primary stream to go through a series of oblique shocks, ultimately terminating in a strong normal shock. This is illustrated in Figure 6. Following the normal shock, the exit flow is fully subsonic. As such, the pressure at the nozzle exit plane must equal the external pressure, giving a constraint that is used to estimate the secondary entrainment.

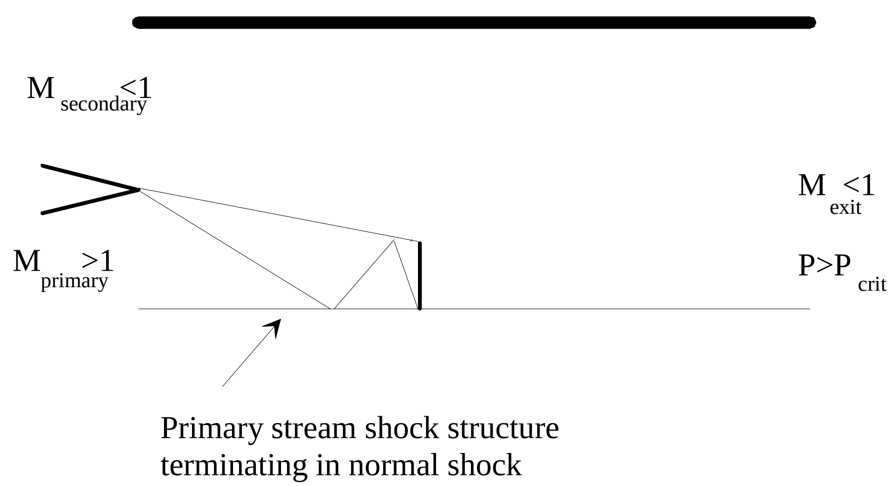


FIGURE 6. Ejector nozzle in subsonic (back pressure dependent mode) with normal shock in primary stream.

This normal shock criterion is dependent upon complete mixing between the two streams. The complete mixing assumption is reasonable for a long ejector, but unrealistic for many short shroud ejectors. Often, due to insufficient mixing, two distinct streams exit the ejector: one supersonic and one subsonic (Figure 7). For this type of flow, though, the secondary entrainment is dominated by the exit pressure because it is subsonic. When this occurs, the entrainment should be predicted, as before, on the basis of the exit pressure.

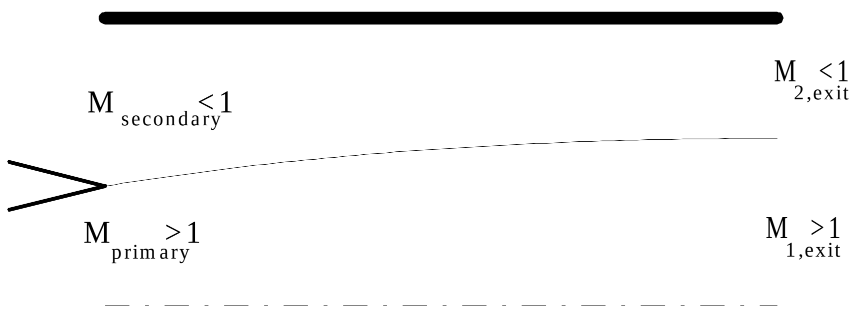


FIGURE 7. Ejector nozzle in back pressure dependent mode due to poorly mixed secondary stream.

Finally, for sufficiently low back pressure, the flow is fully supersonic at the exit plane. This situation may occur if the primary stream accelerates (expands) while the secondary stream also expands but chokes. As shown in Figure 8, this expansion/choking phenomenon causes the streamlines separating the two flows to form an aerodynamic or Fabri choke (ref. 2). Clearly then the exit stream is supersonic, and as such, is independent of the back pressure. The local effect of the subsonic stream does, however, influence the secondary entrainment. The information, though, that is sent into the secondary inlet is no longer a pressure constraint, but the fact that the flow has choked.

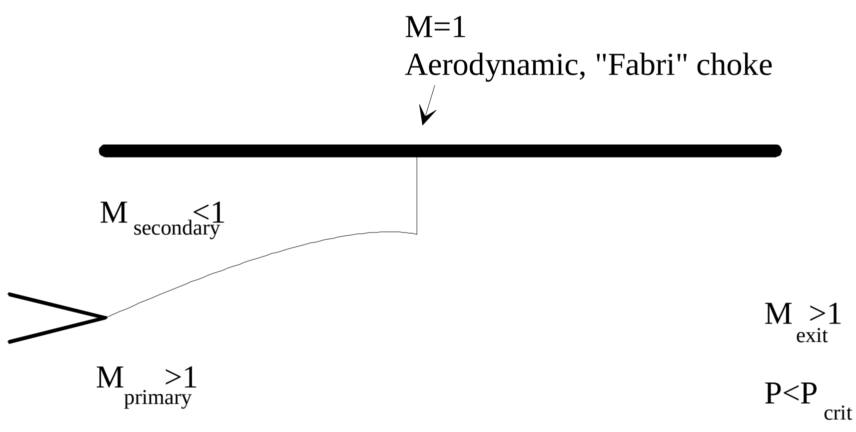


FIGURE 8. Ejector nozzle in back pressure independent mode, exhibiting aerodynamic or Fabri choke.

A special case of the aerodynamic choking phenomenon occurs when the choke forms within the secondary inlet itself. This situation is called saturated supersonic flow and is represented by Figure 9.

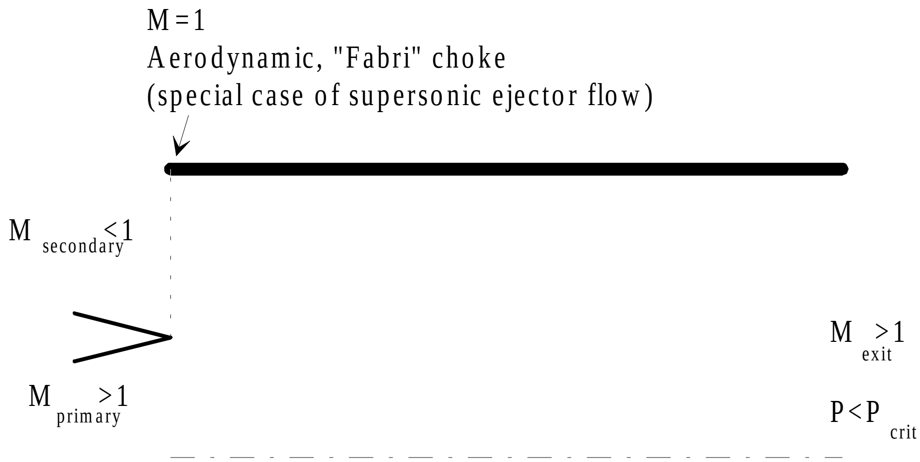


FIGURE 9. Ejector nozzle in back pressure independent mode. Aerochoke in secondary inlet causing classical “supersonic saturated” operation.

As one would expect, this flow is completely specified by upstream conditions, with no chance of any downstream influence. Though this is a valid physical condition, the DREA program will not run in supersonic saturated mode.

DREA Turbulence Model

The "algebraic" turbulence model in the DREA code is composed of two major components: (1) an extended 2-d shear layer model and (2) modifications to permit streamwise vortical flow effects. The "algebraic" definition is used loosely, because the model is the algebraic solution of several closed form partial differential equations and ordinary differential equations that describe the flow. The enhanced 2-d shear layer model, which is motivated by a linear stability argument, is connected to a classical free shear layer through a parabolic partial differential equation. A streamwise mixing ordinary differential equation is developed, which respects the internal geometry and shroud effects (since this is not a free jet). The streamwise vortical enhancement to the flow is modeled via a kinematic, matched asymptotic argument. An analogy is drawn to a wave breaking on the beach, i.e. a growth phase and eventual collapse. This process starts with the ordered growth of mixing, i.e. the elongation and spiraling of filaments of the two streams of fluid and the eventual collapse into a single enhanced 2-d shear layer. These models seem to provide good agreement to a variety of mixing problems and have a physically and mathematically sound theoretical basis. Additions and enhancements can be made within this framework, as well. Additional detail of the turbulence model can be found in reference 1.

The following sections describe how to set up the DREA input for modeling each of the different nozzle flows described above. User specified values indicate whether the nozzle is operating in a back pressure independent or dependent mode, resulting in the execution of the appropriate analyses in the DREA program.

Input File Descriptions

The necessary input information for the DREA program is sub-divided into four separate FORTRAN NAMELIST input files:

1. "control.in" Control volume and parabolic marching code control variables.
2. "flocond.in" Flow field initial conditions and geometry.
3. "expnd.in" Initial guess and control information for the inviscid expansion analysis.
4. "zrdmix.in" Control, grid definition, and turbulence model inputs (vortical) for the marching code.

An additional file containing coordinates that describe the shroud geometry is also required:

“hwall.in” Centerline-Shroud wall height (ft)

DREA assumes a two-dimensional geometry, symmetric about the nozzle centerline (see Figure 10 below). Unless otherwise stated, all geometric inputs (including the vortical ejector geometry) are input for one plane of symmetry. These files and definitions of the input variables are described individually below.

1. File: control.in

The control.in file describes the basic physical arrangement of the ejector/mixer problem. This is where the user specifies the basic flow type, i.e. a mixer or ejector nozzle, and whether the nozzle flow is expected to be subsonic or supersonic at the exit. If the latter is chosen, the user also must specify whether or not to exercise the Fabri choke solution. Output controls are also specified in the control.in file. The user also specifies whether only the control volume solution should be run (for performance results only), or both the control volume and the flowfield (viscous mixing) solutions are desired.

ICNVL	=	Control variable; 0=inviscid and viscous mixing solutions, 1=inviscid (control volume) only.
IEJECT	=	Control variable; 0=mixer solution, 1=ejector solution.
IST	=	Control variable; 0=subsonic solution, 1= supersonic solution.
IFAB	=	Control variable; 0=back pressure constrained solution, 1=Fabri choke solution.
ISPM	=	Control variable; 0=direct solution, 1=iterative closure for inlet static pressure matching.
IPRNT	=	Number of streamwise (x) station printer control, 2=print every station, etc.
IPW	=	Number of cross-stream (y) station printer control, 1=print every variable, etc.
NMAX	=	Maximum number of summations used in analytical (Green's function) expansion for marching analytical/numerical decomposition.

2. File: flocond.in

The flocond.in file describes the geometry and initial conditions at the mixing plane, in addition to the ambient pressure and gas constants. The user can also specify inlet pressure recoveries for both the primary and secondary. The values used in the flocond.in file and the numbering, "1" and “2”, refer to the primary and secondary locations, respectively (see Figure 10). Note that an input value for the secondary Mach number, RM2, is required even for "ejector" cases where it is predicted by the code. For an ejector case, the input value is used as an initial guess for the solver. For many problems, the solver is relatively insensitive to initial guess choice. However, for some flows, especially those operating near flow constraints, e.g. secondary stream choking, secondary stream back flow or exit choking, the choice of secondary Mach number is important. Currently tools are under development to better understand these flow limitations and extend solver convergence, such as the SLIMIT Subsonic Limit analysis (ref. 5).

P01D = Primary stream total pressure (lb/ft^2).
P02D = Secondary stream total pressure (lb/ft^2).
T01D = Primary stream total temperature (deg R).
T02D = Secondary stream total temperature (deg R).
RM1 = Primary stream Mach number.
RM2 = Secondary stream Mach number.
A1D = Primary inlet stream cross-sectional area (ft^2).
A2D = Secondary inlet stream cross-sectional area (ft^2).
A3D = Exit plane cross-sectional area (ft^2).
RG = Real gas constant (air) ((ft lb)/(slug deg R)).
GAM = Specific heat ratio.
PINF = Ambient static pressure (psf).
REC1 = Primary stream nozzle pressure recovery.
REC2 = Secondary stream nozzle pressure recovery.

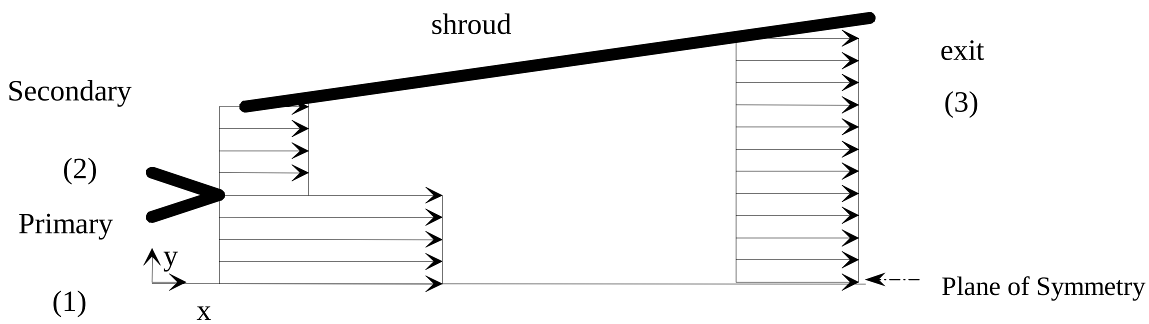


FIGURE 10. Numbering system for program inputs.

3. File: expnd.in

The expnd.in file supplies initial guesses and control parameters to the aero-choke (Fabri choke) solvers. The associated flow problem takes the form illustrated in Figure 11, below. This file is not used for subsonic mixer or ejector problems, though it must exist. For subsonic problems, it does not matter what values are given to the variables in the file.

RM1S = Expanded primary stream Mach number.
RM2S = Expanded secondary stream Mach number.
DXE = Jacobian permutation for Broyden solver, approximately 0.1.
RELX = Relaxation constant (normally not used, set equal to 1.0).
ERRM = Maximum error in expand routines.
NMX = Maximum number of iterations in Broyden solver.
INTT = Number of intervals chosen to search for static pressure constrained expansion problem.

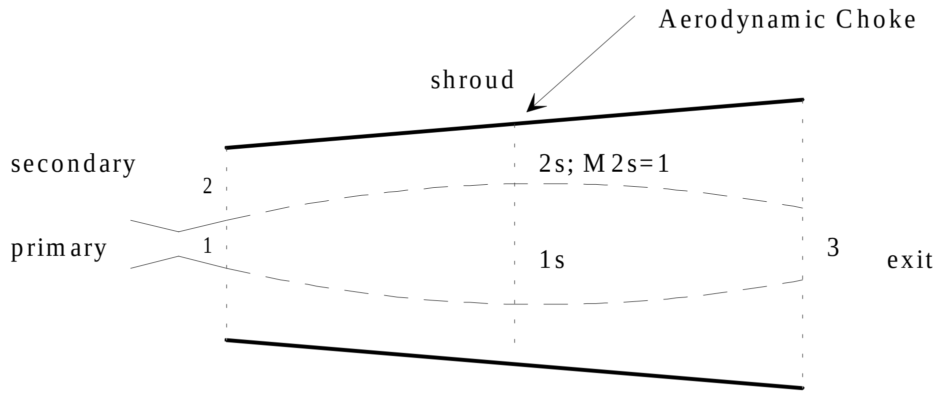


FIGURE 11. Aerodynamic/Fabri choke analysis definitions
(full symmetric geometry displayed).

4. File: zrdmix.in

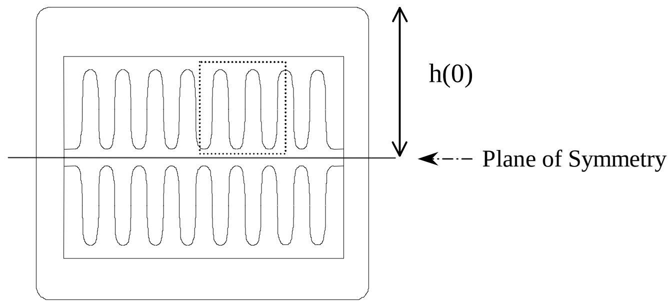
The zrdmix.in file contains parameters describing vortical mixer geometry, if applicable, in addition to other shroud geometry parameters. The numbers of grid points to be used in the analysis along and across the nozzle are also specified in this file.

BWID	=	Width of 2-d ejector mixing section (ft).
RLD	=	Length of mixing section (ft).
RLPRNT	=	Streamwise (x) location for cross-stream profile print out to file yprmw.out (ft).
PR	=	Turbulent Prandtl Number.
CGR	=	Streamwise (x) variable grid control parameter: CGR > 1 cluster points in near field, CGR < 1 cluster points in far field, and CGR=1 constant grid spacing.
REVRT	=	Circulation Reynolds Number.
H0LM	=	Lobe height to wavelength ratio.
H0HY	=	Lobe height to mixing section height (from centerline) ratio (chute penetration).
ALP1	=	Primary flow angle off of mixing chutes.
ALP2	=	Secondary flow angle off of mixing chutes.
IMAX	=	Number of streamwise (x) grid points.
JMAX	=	Number of cross-stream (y) grid points, maximum=30.

In general, the parameters used in the zrdmix.in file are fairly straightforward. However, the parameters used to describe the vortical mixer geometry require further discussion. Additional parameter definitions (not input variables) are

λ	=	Lobe wavelength.
Γ	=	Streamwise vorticity circulation.
h_0	=	Total height of primary chute.

The lobe wavelength and height are described in Figure 12 below. It should be noted that h_0 will not necessarily be consistent with A1, defined in the input file flocond.in. This is due to the fact that the geometry described in flocond.in is a *representation* of the actual ejector geometry as that of a straight splitter mixer. (This representative geometry is also that which is shown in Figure 10, where A1 and A2 are representative of the split of total mixing plane area into primary and secondary flow areas.) The vortical mixer variables defined in this input file, zrdmix.in, give the DREA analysis the information it needs to make the adjustments to the analysis models that account for vortical mixing and turbulence effects on flowfield parameters.



Vortical Mixer/Ejector Cross-section at Mixing Plane

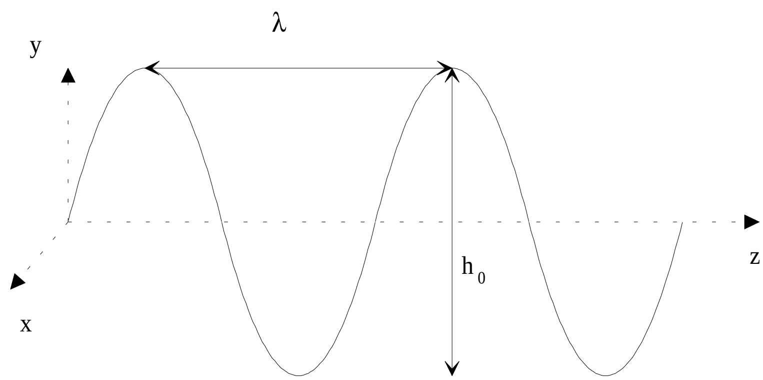


FIGURE 12. Vortical flow geometry input parameter definitions (detail of dashed box).

The parameters HOLM and HOHY are found from the following relations:

$$\mathrm{HOLM} = \frac{h_0}{\lambda}$$

$$\mathrm{HOHY} = \frac{h_0}{h(0)}$$

where h(0) is the height of the duct wall from the nozzle centerline at the mixing plane. (Note this is **not** the same as h_0, which is the height of the primary mixing chute. See Figure 12 above.) HOHY is commonly referred to as the chute penetration.

Additionally, the vortical circulation, Γ, or more importantly it's non-dimensional form, the vortical Reynolds number ($Re_{vort}=\Gamma/(U_{ave}\lambda)$), must be estimated. The vortical Reynolds number is related to the chute geometry using the inviscid/continuity relationship of Skebe and Barber (refs. 3 and 4):

$$\mathrm{Re}_{vort}\left(\frac{\lambda}{h_0}\right) = 2\left[\frac{U_{10}\ \tan\alpha_1 + U_{20}\ \tan\alpha_2}{U_{10} + U_{20}}\right]$$

where:

U_{10}	=	Primary stream initial velocity.
U_{20}	=	Secondary stream initial velocity.
α_1	=	Primary flow angle.
α_2	=	Secondary flow angle.

An alternate to providing the vortical Reynolds number is to specify the flow angles of the primary and secondary off of the mixing chutes (α_1 and α_2). When provided (ALP1 and ALP2 >0), DREA will use these angles to compute the vortical Reynolds number.

For a straight splitter mixer (no vortical chutes), REVRT and HOLM should be set equal to 0. HOHY must have a value greater than zero, even though it is not used for a straight splitter mixer. Setting HOHY equal to zero will cause a divide by zero in the analysis program.

5. File: hwall.in

The hwall.in file is not a NAMELIST input file; rather it is a simple free format input file. This file contains (x,y) coordinates of the nozzle shroud from the mixing plane to the nozzle exit. The file format is as follows:

```
number of data pairs
xlocation (ft)      centerline to shroud distance (h(x)) (ft)
     .                              .
     .                              .
     .                              .
```

The purpose of this data is to provide moderate capability to model variable area ducts of the form found in Figure 13.

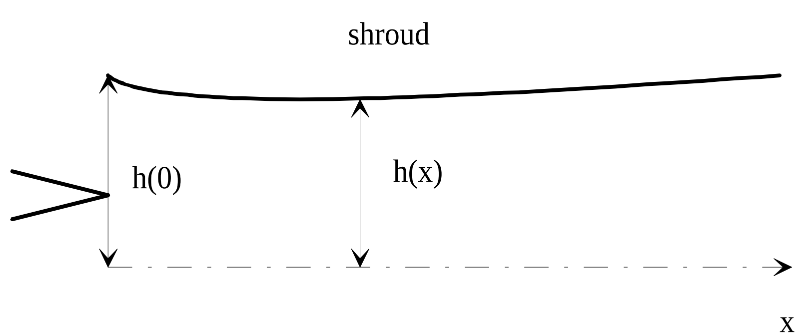


FIGURE 13. Definition of variable nozzle shroud geometry parameters.

Output File Descriptions

The DREA program produces various output files. Three of these output files that the user will find most useful are listed below. Additional output files that are produced, but not listed below, are for testing purposes, and can be ignored.

1. ejectd.out Main output file. Contains control volume and flowfield marching results.
2. yprmw.out Contains cross-stream profile information at x location specified in RLPRNT (flocond.in).
3. zorder.ave Contains centerline Mach number, velocity, and pressure values along the nozzle duct.

It is important to note that results are virtually always computed and presented in dimensionless form. The input files use dimensional quantities only to ease interfacing with existing codes. Spatial position, x and y are scaled by the nozzle centerline to shroud distance:

$$x_{non-diim} = \frac{x}{h(0)} \quad y_{non-\mathrm{dim}} = \frac{y}{h(0)}$$

where h(0) is the nozzle shroud to centerline distance as shown in Figure 12 above. Additionally, the dependent variables, both conservative and primitive variables, are scaled by the nozzle mixing plane, area averaged conditions. These conditions were chosen because they are readily available. In other words:

$$f_{non-\mathrm{dim}}(x,y) = \frac{f(x,y)}{f_{ave}} = \frac{f(x,y)}{f_{10}A_{10} + f_{20}A_{20}}\left(A_{10} + A_{20}\right)$$

Descriptions of the output variables that will be of interest to the user are included in the example problems below. Output variables will differ depending on the type of analysis run, whether mixer or ejector, subsonic or supersonic, Fabri choke, etc.

Example Problems

Three ejector and one mixer example problems are presented below to demonstrate the capabilities of the DREA code and to aid the user in setting up problems correctly. All three are based on a single nozzle geometry, with input flow parameters modified to produce different operating conditions. All information used in these examples is **fictional**. These problems are presented solely for the purpose of demonstration, and must be modified by the user to meet specific design and analysis requirements. The example problems include:

(a) A subsonic ejector problem: in this problem, both the primary and the secondary flows are subsonic; the secondary flow is predicted by DREA.
(b) A supersonic/subsonic ejector problem: this problem starts with a supersonic primary and subsonic secondary. The exit flow is also mixed subsonic/supersonic. This demonstrates a nozzle with incomplete mixing.
(c) A supersonic ejector problem with Fabri choke: in this example, the primary flow is supersonic. The secondary flow is initially subsonic, then goes through a Fabri choke in the mixing duct to produce fully supersonic exit flow.

(d) A supersonic/subsonic mixing problem: this is the same as example (b), except that it is run as a mixer. Initial flow properties for the secondary are completely specified by the user.

These examples should provide a useful presentation of the control and input parameters needed to use the DREA computer program. Comments that appear in italics are provided as additional information to the user but should not be included in input files or looked for in output files.

The mixer/ejector nozzle geometry used for the examples is shown in Figures 14 and 15. It includes a vortical chute arrangement with 16 chutes in one bank (there are two "chute banks", one above the nozzle centerline and one below), with 8 hot (primary) and 8 cold (secondary) chutes assumed. A 90% lobe penetration is also assumed (HOHY=.90). Additional data is given below. All length dimensions are ft, and all area dimensions are ft^2.

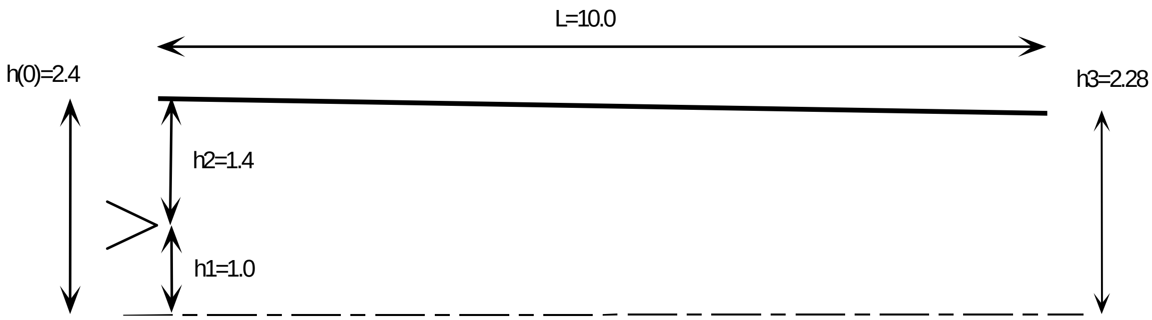
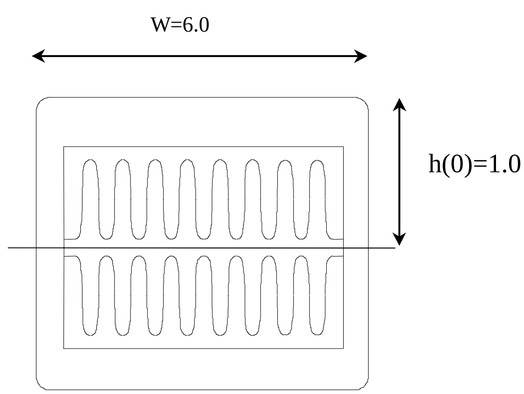


FIGURE 14. Example Mixer/ejector Nozzle Geometry.



Vortical Mixer/Ejector Cross-section

FIGURE 15. Cross-section of Example Mixer/ejector Nozzle.

The geometric parameters are given as:

A1 = 6.0	λ = 0.75	HOLM = 2.88
A2 = 8.4	h(0) = 2.4	HOHY = 0.90
A3 = 13.68	h_0 = 2.16	Secondary Inlet Recovery = 0.98

(a) Subsonic Ejector Problem

This example problem models a subsonic ejector nozzle. Both the primary and secondary flows are subsonic at the mixing plane. The necessary input files for this problem are presented below.

File: control.in

```
&cntrl
  icnvl=0,        ←Compute performance, i.e. control volume, and mixing solutions.
  ieject=1,       ←Ejector flow; i.e. compute secondary conditions.
  ist=0,          ←Subsonic exit condition.
  ifab=0,         ←Back pressure constrained.
  ispm=0,         ←Direct solution (no inlet stream static pressure match).
  iprnt=2,        ←Streamwise print control.
  ipw=1,          ←Cross-stream printer control.
  nmax=6,         ←Max. number of terms used in singularity solution.
&end
```

File: expnd.in

```
&exd              ←expnd.in file is not used for this subsonic model.
  rm1s=1.8,          (It must exist, but its contents are ignored.)
  rm2s=0.8,
  dxe=.1,
  relx=1.,
  errm=1.d-6,
  nmx=500,
  intt=100,
&end
```

File: flocond.in

```
&floc             ←This file contains mixing plane information.
  p01d=4233.6,    ←Primary stream total pressure in lb/ft^2.
  p02d=2116.8,    ←Secondary stream total pressure in lb/ft^2.
  t01d=518.69,    ←Primary stream total temperature in deg. R.
  t02d=518.69,    ←Secondary stream total temperature in deg. R.
  rm1=0.95,       ←Primary stream Mach number.
  rm2=0.4,        ←Initial guess of secondary stream Mach number.
  a1d=6.00,       ←Primary stream cross-sectional area in ft^2.
  a2d=8.40,       ←Secondary stream cross-sectional area in ft^2.
  a3d=13.68,      ←Exit plane cross-sectional area in ft^2.
  rg=1718.,       ←Air ideal gas constant (ft lb)/(slug deg. R).
  gam=1.4,        ←Specific heat ratio.
  pinf=2116.8,    ←Ambient static pressure.
  rec1=1.0,       ←Primary stream inlet recovery.
  rec2=0.98,      ←Secondary stream inlet recovery.
&end
```

File: hwall.in

```
3                           ←Total number of data pairs to describe shroud.
0.0,        2.4,            ←Data pair: x location (ft) and centerline to
5.0,        2.34,               shroud distance (ft).
10.0,       2.28,
```

File: zrdmix.in

```
&zrd
  BWID=6.0,                 ←Width in feet of 2-d ejector (ft).
  RLD=10.0,                 ←Length of ejector (ft).
  RLPRNT=0.3333,            ←Physical location for cross-stream profile print out.
  PR=1.D0,                  ←Turbulent Prandtl number.
  CGR=1.0,                  ←Streamwise grid cluster control (set to constant spacing).
  REVRT=2.0D0,              ←Vortical lobe geometry parameter.
  H0LM=2.88,                ←Vortical lobe geometry parameter.
  H0HY=0.90,                ←Vortical lobe geometry parameter.
  ALP1=-10.0,               ←Negative number indicates this will not be used.
  ALP2=-10.0,               ←Negative number indicates this will not be used.
  IMAX=5,                   ←Number of streamwise grid points.
  JMAX=20,                  ←Number of cross-stream grid points.
&end
```

The main output file, ejectd.out, is printed below. Comments in italics highlight the different sections of the output file and significant quantities. Flowfield data has been printed only for the first and last analysis stations to save space.

File ejectd.out

```
****************************************************

 ELEMENTARY INTEGRAL (C.V.) MIXING ANALYSIS
 VARIABLE AREA EXTENSIONS
 CODE AND ANALYSIS, LAWRENCE J. DE CHANT

 ****************************************************

 ****************************************************

 SUBSONIC SOLUTION                        ←Denotes a back pressure constrained
                                              solution.
 ****************************************************


 ---------------------
 EJECTOR SOLUTION                         ←Ejector solution (entrainment computed).
 ---------------------
                                          Primary stream quantities at mixing plane.
 P1D=   2368.529796284120                 ←Static pressure (lb/ft^2).
 T1D=   439.3816179584923                 ←Static temperature (deg R).
 U1D=    976.6077013986594                ←Velocity (ft/s).
 RM1=  0.9500000000000000                 ←Mach number.
 RH1D=  3.1377172788874829E-03            ←Density (slug/ft^3).
```

```
RMD1D=   18.38591315623897                        ←Mass flow rate (slug/s).
P01D=   4233.600000000000                         ←Total pressure (lb/ft^2).
T01D=   518.6900000000001                         ←Total temperature (deg R).

                                   Secondary stream quantities at mixing plane (computed).
P2D=   1746.076141682662                          (similar variable definitions as for primary
T2D=   493.7694766463152                          stream above, but for secondary stream)
U2D=   547.4433430515097
RM2=  0.5023442802308902                          ←Important quantity to look at.  If the
RH2D=  2.0583336738685927E-03                         value of RM2  is very small, the ejector
RMD2D=   9.465296967320194                            did not entrain any secondary flow.
P02D=   2074.464000000000                             If this value is >1, the secondary
T02D=   518.6900000000001                             duct choked and the subsonic solution
                                                      may not be valid.
SUBSONIC MACH=  0.7294869565542920                ←Exit plane ideally mixed conditions; note
SUPERSONIC MACH=   1.487790976286235                  only the subsonic solutions are meaningful
                                                      for this example.
SUB PRESSURE=   2116.800462188400                 ←Exit plane ideally mixed static pressure (lb/ft^2).
SUP PRESSURE=   908.9267264918863

SUB VELOCITY=   801.9748760362460                 ←Exit plane ideally mixed velocity (ft/s).
SUP VELOCITY=   1395.260145545990

SUB TEMPERATURE=   468.7959343421206              ←Exit plane ideally mixed static temp. (deg. R).
SUP TEMPERATURE=   359.5261792938450

SUB DENSITY=  2.5386171482543775E-03              ←Exit plane ideally mixed density (slug/ft^3).
SUP DENSITY=  1.4591595547782999E-03


SUBSONIC TOTAL PRESSURE=   3015.879996287564          ←Exit plane ideally mixed total pressure
SUPERSONIC TOTAL PRESSURE=   3278.306981806214            (lb/ft^2)
PRIMARY INLET RECOVERY=   1.000000000000000           ←Primary and secondary inlet recovery:
SECONDARY INLET RECOVEY=  0.9800000000000000              input in flocond.in.

NPR=   2.000000000000000                          ←Primary stream nozzle pressure ratio.


PUMPING RATIO W2/W1=  0.5148124483612224          ←Entrainment ratio w2/w1.

CORRECTED PUMPING RATIO W2/W1*(T02/T01)**.5           ←Temperature corrected entrainment.
W2/W1 CORR.=  0.5148124483612224

DIM. SHROUD LENGTH   4.166666666666667            ←Dimensionless shroud length.
SECONDARY TO TOTAL MASS FLOW W2/(W1+W2)=  0.3398522694464022         ←Mass flow ratio.


P02/P01=  0.4899999999999999                      ←Total pressure ratio between secondary and
                                                      primary.

SUBSONIC CFG=   1.147556040861858                 ←Gross thrust coefficient
SUPERSONIC CFG=   1.147556040861857                   (does not include ram drag or divergence
                                                      drag; includes expansion loss/thrust).
GEOMETRY
PRIMARY AREA=   6.000000000000000                 ←Dimensional geometry (from input).
SECONDARY AREA=   8.400000000000000
NET INLET AREA=   14.40000000000000
EXIT AREA=   13.68000000000000
```

MASS CONSERVATION RESIDUALS ←*Solution conservation values; should be approximately zero.*
SUBSONIC RESMB= 6.3780239045973861E-17

ENERGY CONSERVATION RESIDUALS
SUBSONIC RESEB= 0.0000000000000000E+00

VARIABLE AREA MOMENTUM RESIDUAL
SUBSONIC RESMOMB= 0.0000000000000000E+00

SUBSONIC ENTROPY GENERATION S/R= 2.693976710385581

SUPERSONIC ENTROPY GENERATION S/R= 0.3701980504541487

SUBSONIC STEADY SOLUTION ←*Exit condition parameters and match.*
PINF= 2116.800000000000 ←*Ambient static pressure (input).*
P3B= 2116.800462188400 ←*Exit static pressure (computed).*
ERROR= 2.1834297029675263E-07 ←*(P3B-PINF)/PINF*.

DEGREE OF MIXING IN PRESSURE CONSTRAINT ←*Estimation of pressure constraint matching. Used as test output.*
1.000000000000000

TOTALLY UNMIXED (COMPARISON)
0.8099106039721308
PERCENT DIFFERENCE
19.00893960278692

PARABOLIC MARCHING CODE ←*Mixing/profile portion of output.*
STREAMWISE CRANK-NICOLSON, DX**2
CROSS-STREAM COMPACT, KRIESS DY**4
CONSERVATIVE FLUX, PRIMITIVE VARIABLE DECODE

CODE AND ANALYSIS: LAWRENCE J. DE CHANT; TEXAS A&M

AVERAGE VALUES ←*Area averaged quantities.*

RMAV= 0.6888674968013525 ←*Average Mach number.*
UAVE= 726.2618256961554 ←*Average velocity.*
GAVE= 3612.205317238478 ←*Average momentum flux.*
TAVE= 471.1078688597223 ←*Average static temperature.*
ROAVE= 2.5080768426264635E-03 ←*Average density.*
PAVE= 2005.431831099937 ←*Average static pressure.*
RUAVE= 1.934111814136053 ←*Average specific mass flow rate.*
RUHAVE= 6032268.399184742 ←*Term from energy equation.*
PTOAVE= 2974.104000000000 ←*Average total pressure.*
PT0AVE/PAVE= 1.483024231428882 ←*Ratio of ave. total to static pressures.*
T0AVE= 518.6900000000002 ←*Average total temperature.*

GEOMETRY ←*Non-dimensionalized geometry variables.*
RL= 4.166666666666667 ←*Mixing length/h(0).*
HY/EPS2= 1.000000000000000 ←*Test variable, always equal to 1.0.*
EPS**.5= 1.5158608859448449E-02 ←*Test variable.*
DX0C= 0.8333333333333334 ←*Streamwise step size.*

DIMENSIONLESS INLET QUANTITIES ←*Non-dimensionalized inlet quantities.*

CONSERVATIVE VALUES ←*Conservative variables used in parabolic mixing flow analysis.*
G10= 1.484181192111113
G20= 0.6541562913492049
GC10= 1.835695533004734
GC20= 0.4030746192823326
RU10= 1.584354553328635
RU20= 0.5826038904795466
RUH10= 1.584354553328635
RUH20= 0.5826038904795466

PRIMITIVE INLET VARIABLES ←*Non-dimensionalized input quantities at mixing plane.*
RM1= 0.9500000000000000 ←*Primary Mach number.*
RM2= 0.5023442802308902 ←*Secondary Mach number.*
U1= 1.344704715083346 ←*Primary velocity/Average velocity.*
U2= 0.7537823463690386 ←*Secondary velocity/Average velocity.*
P1= 1.181057246401156 ←*Primary static pressure/Average static press.*
P2= 0.8706733954277454 ←*Secondary static press./Average static press.*
T1= 0.9326560794282193 ←*Primary static temp./Average static temp.*
T2= 1.048102800408415 ←*Secondary static temp./Average static temp.*
PTO1= 2.111066521606951 ←*Primary total pressure/Average static press.*
PT02= 1.034422595587406 ←*Secondary total pressure/Ave. static press.*
RHO1= 1.251045113754034 ←*Primary density/Average density.*
RHO1= 0.8206820616042614 ←*Secondary density/Average density.*

HSP= 0.4166666666666667 ←*Cross-stream grid information.: Splitter plate height ratio; grid point counter.*
JSP= 9
LOWER STREAM GRID SPACING
DY10= 5.2083333333333336E-02 ←*Lower stream grid spacing.*
UPPER STREAM GRID SPACING
DY20= 5.8333333333333327E-02 ←*Upper stream grid spacing.*
JUMP DELTA= 7.6733603947176556E-06 ←*Thickness of splitter plate.*

X LOCATION= 0.0000000000000000E+00 ←*First station location for profile output.*
GRID POINT I= 0
LOCAL TURBULENT REYNOLDS NUMBER
0.0000000000000000E+00

Y LOCATION ←*Cross-stream locations for output data.*

0.000000	0.052083	0.104167	0.156250	0.208333	0.260417
0.312500	0.364583	0.416663	0.416671	0.475000	0.533333
0.591667	0.650000	0.708333	0.766667	0.825000	0.883333
0.941667	1.000000				

VELOCITY/UAVE ←*Dimensionless velocity output.*

1.344705	1.344705	1.344705	1.344705	1.344705	1.344705
1.344705	1.344705	1.344705	0.753782	0.753782	0.753782
0.753782	0.753782	0.753782	0.753782	0.753782	0.753782
0.753782	0.753782				

PRESSURE/PAVE ←*Dimensionless static pressure output.*

1.074832	1.074832	1.074832	1.074832	1.074832	1.074832
1.074832	1.074832	1.074832	1.391012	1.391012	1.391012
1.391012	1.391012	1.391012	1.391012	1.391012	1.391012
1.391012	1.391012				

```
MACH NUMBER                                        ←Mach number output.
  0.950000   0.950000   0.950000   0.950000   0.950000   0.950000
  0.950000   0.950000   0.950000   0.502344   0.502344   0.502344
  0.502344   0.502344   0.502344   0.502344   0.502344   0.502344
  0.502344   0.502344

TOTAL PRESSURE                                     ←Dimensionless total pressure output.
  1.921196   1.921196   1.921196   1.921196   1.921196   1.921196
  1.921196   1.921196   1.921196   1.652622   1.652622   1.652622
  1.652622   1.652622   1.652622   1.652622   1.652622   1.652622
  1.652622   1.652622


FULLY DEVELOPED APPROXIMATION                        ←Wall skin friction and heat transfer (skin
APPROXIMATE WALL FRICTION=  0.0000000000000000E+00         friction calculation not
APPROXIMATE WALL HEAT TRANSFER=  0.0000000000000000E+00    currently implemented).


X LOCATION=  4.1666666666666666E-03                ←Second station for flowfield output.
GRID POINT I=          1
LOCAL TURBULENT REYNOLDS NUMBER
  99156.37476231223

Y LOCATION
  0.000000   0.052083   0.104167   0.156250   0.208333   0.260417
  0.312500   0.364583   0.416663   0.416671   0.474995   0.533323
     .
     .
     .

X LOCATION=   4.166666666666668                    ←Exit station for flowfield output.
GRID POINT I=          5
LOCAL TURBULENT REYNOLDS NUMBER
  61.79925366317428

Y LOCATION                                         ←Cross-stream locations at exit plane.
  0.000000   0.052083   0.104167   0.156250   0.208333   0.260417
  0.312500   0.364583   0.416663   0.416671   0.470000   0.523333
  0.576667   0.630000   0.683333   0.736667   0.790000   0.843333
  0.896667   0.950000

VELOCITY/UAVE                                      ←Exit dimensionless velocity profile.
  1.084632   1.079301   1.064155   1.041165   1.012504   0.980004
  0.945093   0.908918   0.872478   0.872472   0.835871   0.800982
  0.768776   0.740114   0.715664   0.695824   0.680700   0.670171
  0.663998   0.661969

PRESSURE/PAVE                                      ←Exit dimensionless static pressure profile.
  1.154341   1.156823   1.164230   1.176473   1.193393   1.214713
  1.239970   1.268446   1.299138   1.299143   1.331569   1.363534
  1.393585   1.420492   1.443393   1.461848   1.475793   1.485424
  1.491036   1.492876

MACH NUMBER                                        ←Exit Mach number profile.
  0.743188   0.739135   0.727655   0.710330   0.688891   0.664788
  0.639133   0.612792   0.586496   0.586493   0.560308   0.535548
  0.512857   0.492789   0.475759   0.461998   0.451543   0.444280
  0.440028   0.438632
```

TOTAL PRESSURE ←*Exit dimensionless total pressure profile.*

1.665720	1.662988	1.655920	1.647095	1.639131	1.633871
1.632235	1.634357	1.639784	1.639785	1.647890	1.657485
1.667483	1.676977	1.685324	1.692167	1.697380	1.700993
1.703101	1.703792				

It can be seen from the flowfield information at the exit station of the nozzle that the flow is not fully mixed. This is common for nozzles of realistic length. One of the benefits of the DREA method is that it does not pre-assume that the exit profile will be fully mixed, thus allowing the variations in exit velocity to be computed. The ability to estimate exit profile information can be useful in acoustic analyses.

As indicated in the output file notes, an important parameter to look at for a subsonic ejector nozzle case is the secondary Mach number at the mixing plane. The value of this parameter can indicate whether or not the nozzle conditions are consistent with subsonic ejector operation. Typically, specification of parameters that are inconsistent with subsonic operation will cause convergence failure. Information concerning the range of parameters that are consistent with subsonic operation can be estimated using a stand-alone code named the SLIMIT Subsonic Limit analysis (ref. 5).

The output file zorder.ave is presented below, followed by a plot of the normalized centerline velocity along the nozzle duct for this problem (Figure 16). Figure 16 shows the decay of the primary stream velocity due to mixing.

File zorder.ave:

Centerline and Wall Flowfield Parameters

X	U/Uave	Mach	U/Uave Wall	Mach Wall	P/Pave	Y Wall
0.0000	1.3447	0.9500	0.7538	0.5023	1.0748	1.0000
0.0042	1.3519	0.9560	0.7605	0.5071	1.0780	0.9999
1.0448	1.3519	0.9560	0.7605	0.5071	1.0904	0.9875
2.0854	1.3441	0.9495	0.7606	0.5071	1.0975	0.9750
3.1260	1.2783	0.8953	0.7647	0.5100	1.0750	0.9625
4.1667	1.0846	0.7432	0.6620	0.4386	1.1543	0.9500

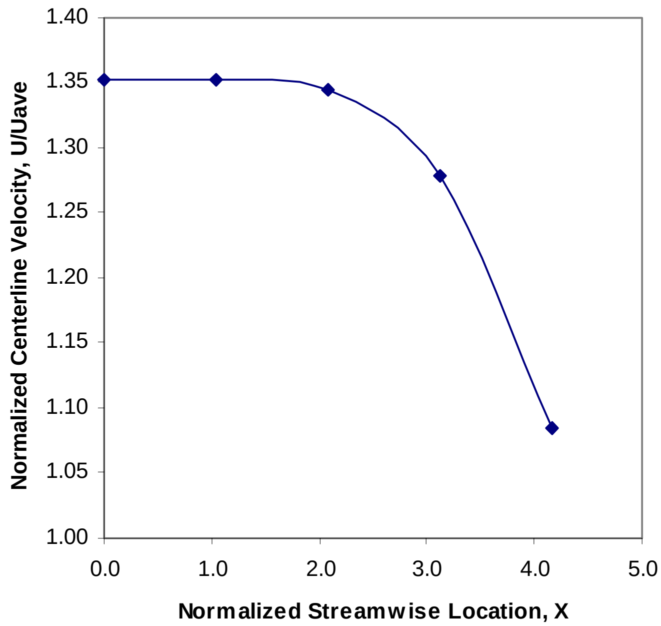


FIGURE 16. Normalized centerline velocity along the length of sample subsonic ejector.

(b) Supersonic/subsonic Ejector Problem

The next example problem models an ejector nozzle with supersonic primary and subsonic secondary flow at the mixing plane and combined supersonic/subsonic flow at the nozzle exit. The only inputs that are different from the previous example are the total conditions (pressure and temperature) and Mach number of the primary flow. These are contained in the input file flocond.in, which is given below for this problem. The initial guess for the secondary Mach number has also been changed. The DREA program tends to be sensitive to this initial guess when running some ejector problems. If the user is having problems getting the program to converge upon a solution, this value should be modified and the program re-executed. If the user is unable to find an initial value for the secondary Mach number that will result in a converged solution, then there is another problem with the model, for example, choking of the secondary duct. One can often gain insight into the appropriate secondary Mach number guess by running the model in "mixer" mode and examining the exit pressure and Mach number. Here again, the SLIMIT code can be of use (ref. 5). Analysis is underway to improve and “globalize” the secondary Mach number iteration process. Possible globalization methodologies are likely to combine gradient methods with the fast quasi-Newton, i.e. secant methods already employed. Since the necessity to respect certain flow operating conditions strongly influences the iteration, some form of penalty function modification of an objective function may be desirable.

File flocond.in:

&floc	←*This file contains mixing plane information.*
p01d=6350.4,	←*Primary stream total pressure in lb/ft^2.*
p02d=2116.8,	←*Secondary stream total pressure in lb/ft^2.*
t01d=648.36,	←*Primary stream total temperature in deg. R.*
t02d=518.69,	←*Secondary stream total temperature in deg. R.*
rm1=1.30,	←*Primary stream Mach number.*

```
  rm2=0.55,              ←Initial guess of secondary stream Mach number.
  a1d=6.00,              ←Primary stream cross-sectional area in ft^2.
  a2d=8.40,              ←Secondary stream cross-sectional area in ft^2.
  a3d=13.68,             ←Exit plane cross-sectional area in ft^2.
  rg=1718.,              ←Air ideal gas constant (ft lb)/(slug deg. R).
  gam=1.4,               ←Specific heat ratio.
  pinf=2116.8,           ←Ambient static pressure.
  rec1=1.0,              ←Primary stream inlet recovery.
  rec2=0.98,             ←Secondary stream inlet recovery.
&end
```

The main output file for this sample problem, ejectd.out, is printed below. Comments in italics highlight portions of this output file that are significant. For the most part, this output file is similar to that from the fully subsonic sample problem above. As for the previous example problem, flowfield data has been printed only for the first and last analysis stations to save space.

File ejectd.out:

```
*****************************************************

 ELEMENTARY INTEGRAL (C.V.) MIXING ANALYSIS
 VARIABLE AREA EXTENSIONS
 CODE AND ANALYSIS, LAWRENCE J. DE CHANT

 *****************************************************

 *****************************************************

 SUBSONIC SOLUTION                          ←Denotes a back pressure constrained
                                                solution.
 *****************************************************


 ---------------------
 EJECTOR SOLUTION                           ←Ejector solution (entrainment computed).
 ---------------------
                                            Primary stream quantities at mixing plane.
 P1D=   2291.947601406177                   ←Static pressure (lb/ft^2).
 T1D=   484.5739910313901                   ←Static temperature (deg. R).
 U1D=   1403.456641245643                   ←Velocity (ft/s).
 RM1=   1.300000000000000                   ←Mach number.
 RH1D=  2.7530964403726546E-03              ←Density (slug/ft^3).
 RMD1D=   23.18310889938445                 ←Mass flow rate (slug/s).
 P01D=   6350.400000000000                  ←Total pressure (lb/ft^2).
 T01D=   648.3600000000000                  ←Total temperature (lb/ft^2).

                                  Secondary stream quantities at mixing plane (computed).
 P2D=   1437.189873574343                   (similar variable definitions as for primary
 T2D=   467.0542991258854                   stream above, but for secondary stream)
 U2D=   788.0170929060504
 RM2=  0.7434920914793973                   ←Important quantity to look at.  If the
 RH2D=  1.7911155939844034E-03                  value of RM2 is very small, the ejector
 RMD2D=   11.85600950881438                     did not entrain any secondary flow.
 P02D=   2074.464000000000                      If this value is >1, the secondary
 T02D=   518.6900000000001                      duct choked and the subsonic solution
                                                is not valid.
```

SUBSONIC MACH= 0.9241772099881135 ←*Exit plane ideally mixed conditions; again, only the subsonic solutions are meaningful since this is the subsonic solution.*
SUPERSONIC MACH=   1.126115393585731

SUB PRESSURE=   2206.005886083670 ←*Exit plane ideally mixed static pressure.*
SUP PRESSURE=   1749.605051779618

SUB VELOCITY=   1052.524891685357 ←*Exit plane ideally mixed velocity.*
SUP VELOCITY=   1230.713262195801

SUB TEMPERATURE=   516.2910217447167 ←*Exit plane ideally mixed static temperature.*
SUP TEMPERATURE=   482.1881885489173

SUB DENSITY= 2.4335187558609341E-03 ←*Exit plane ideally mixed density.*
SUP DENSITY= 2.0811826309216435E-03

SUBSONIC TOTAL PRESSURE=   3831.096075833489 ←*Exit plane ideally mixed total pressure.*
SUPERSONIC TOTAL PRESSURE=   3859.485534020342
PRIMARY INLET RECOVERY=   1.000000000000000 ←*Primary and secondary inlet recovery: input in flocond.in.*
SECONDARY INLET RECOVEY= 0.9800000000000000

NPR=   3.000000000000000 ←*Primary stream nozzle pressure ratio.*

PUMPING RATIO W2/W1= 0.5114072301635599 ←*Entrainment ratio w_2/w_1.*

CORRECTED PUMPING RATION W2/W1*(T02/T01)**.5 ←*Temperature corrected entrainment.*
W2/W1 CORR.= 0.4574174142035992

DIM. SHROUD LENGTH   4.166666666666667 ←*Dimensionless shroud length.*
SECONDARY TO TOTAL MASS FLOW W2/(W1+W2)= 0.3383649488749746 ←*Mass flow ratio.*

P02/P01= 0.3266666666666667 ←*Total pressure ratio between secondary and primary.*

SUBSONIC CFG=   1.133925192134883 ←*Gross thrust coefficient (does not include ram drag or divergence drag; includes expansion loss/thrust).*
SUPERSONIC CFG=   1.133925192134884

GEOMETRY
PRIMARY AREA=   6.000000000000000 ←*Dimensional geometry (from input).*
SECONDARY AREA=   8.400000000000000
NET INLET ARE=   14.40000000000000
EXIT AREA=   13.68000000000000

MASS CONSERVATION RESIDUALS ←*Solution conservation variables; should be approximately zero.*
SUBSONIC RESMB= -5.0696390779757727E-17

ENERGY CONSERVATION RESIDUALS
SUBSONIC RESEB= 0.0000000000000000E+00

VARIABLE AREA MOMENTUM RESIDUAL
SUBSONIC RESMOMB= 1.4551915228366852E-11

SUBSONIC ENTROPY GENERATION S/R=   5.109105765809208

SUPERSONIC ENTROPY GENERATION S/R=   4.850413730315270

SUBSONIC STEADY SOLUTION ←*Exit condition parameters and match.*
PINF= 2116.800000000000 ←*Ambient static pressure (input).*
P3B= 2206.005886083670 ←*Exit static pressure (computed).*
ERROR= 4.2141858505134924E-02 ←*(P3B-PINF)/PINF.*

DEGREE OF MIXING IN PRESSURE CONSTRAINT ←*Estimation of pressure constraint matching. Used as test output.*
0.9595611498018987

TOTALLY UNMIXED (COMPARISON)
0.7043531891931452
PERCENT DIFFERENCE
26.59632068904011

XPN1=XCRIT/HW=nan

\---
PARABOLIC MARCHING CODE ←*Mixing/profile portion of output.*
STREAMWISE CRANK-NICOLSON, DX**2
CROSS-STREAM COMPACT, KRIESS DY**4
CONSERVATIVE FLUX, PRIMITIVE VARIABLE DECODE

CODE AND ANALYSIS: LAWRENCE J. DE CHANT; TEXAS A&M
\---

AVERAGE VALUES ←*Area averaged quantities.*

RMAV= 0.9753703866963153 ←*Average Mach number.*
UAVE= 1044.450238047548 ←*Average velocity.*
GAVE= 4701.618530737918 ←*Average momentum flux.*
TAVE= 474.3541707531790 ←*Average static temperature.*
ROAVE= 2.1919409466461749E-03 ←*Average density.*
PAVE= 1793.338926837607 ←*Average static pressure.*
RUAVE= 2.433272111680475 ←*Average specific mass flow rate.*
RUHAVE= 8844368.893857414 ←*Term from energy equation.*
PTOAVE= 3856.104000000000 ←*Average total pressure.*
PT0AVE/PAVE= 2.150237159464271 ←*Ratio of ave. total to static pressures.*
T0AVE= 572.7191666666668 ←*Average total temperature.*

GEOMETRY ←*Non-dimensionalized geometry variables.*
RL= 4.166666666666667 ←*Mixing length/h(0).*
HY/EPS2= 1.000000000000000 ←*Test variable, always equal to 1.0.*
EPS**.5= 1.5286192896720065E-02 ←*Test variable.*
DX0C= 0.8333333333333334 ←*Streamwise step size.*

DIMENSIONLESS INLET QUANTITIES ←*Non-dimensionalized inlet quantities.*

CONSERVATIVE VALUES ←*Conservative variables used in parabolic mixing flow analysis.*
G10= 1.640859541431655
G20= 0.5422431846916752
GC10= 1.755503288671175
GC20= 0.4603547938063035
RU10= 1.587924122700061
RU20= 0.5800541980713849
RUH10= 1.703181745866178
RUH20= 0.4977273243813015

PRIMITIVE INLET VARIABLES ←*Non-dimensionalized input quantities at mixing plane.*
RM1= 1.300000000000000 ←*Primary Mach number.*
RM2= 0.7434920914793973 ←*Secondary Mach number.*
U1= 1.343727628296785 ←*Primary velocity/Average velocity.*
U2= 0.7544802655022964 ←*Secondary velocity/Average velocity.*
P1= 1.278033709694699 ←*Primary static pressure/Average static press.*
P2= 0.8014044930752152 ←*Secondary static press./Average static press.*
T1= 1.021544704164789 ←*Primary static temp./Average static temp.*
T2= 0.9846109255965793 ←*Secondary static temp./Average static temp.*
PTO1= 3.541104196738964 ←*Primary total pressure/Average static press.*
PT02= 1.156760704268061 ←*Secondary total pressure/Ave. static press.*
RHO1= 1.256008490824120 ←*Primary density/Average density.*
RHO1= 0.8171367922684857 ←*Secondary density/Average density.*

HSP= 0.4166666666666667 ←*Cross-stream grid information.: Splitter plate*
JSP= 9 *height ratio; grid point counter.*
LOWER STREAM GRID SPACING
DY10= 5.2083333333333336E-02 ←*Lower stream grid spacing.*
UPPER STREAM GRID SPACING
DY20= 5.8333333333333327E-02 ←*Upper stream grid spacing.*
JUMP DELTA= 7.6733603947176556E-06 ←*Thickness of splitter plate.*

X LOCATION= 0.0000000000000000E+00 ←*First station location for profile output.*
GRID POINT I= 0
LOCAL TURBULENT REYNOLDS NUMBER
0.0000000000000000E+00

Y LOCATION ←*Cross-stream location for output data.*

0.000000	0.052083	0.104167	0.156250	0.208333	0.260417
0.312500	0.364583	0.416663	0.416671	0.475000	0.533333
0.591667	0.650000	0.708333	0.766667	0.825000	0.883333
0.941667	1.000000				

VELOCITY/UAVE ←*Dimensionless velocity output.*

1.343728	1.343728	1.343728	1.343728	1.343728	1.343728
1.343728	1.343728	1.343728	0.754480	0.754480	0.754480
0.754480	0.754480	0.754480	0.754480	0.754480	0.754480
0.754480	0.754480				

PRESSURE/PAVE ←*Dimensionless static pressure output.*

1.278034	1.278034	1.278034	1.278034	1.278034	1.278034
1.278034	1.278034	1.278034	0.801404	0.801404	0.801404
0.801404	0.801404	0.801404	0.801404	0.801404	0.801404
0.801404	0.801404				

MACH NUMBER ←*Mach number output.*

1.300000	1.300000	1.300000	1.300000	1.300000	1.300000
1.300000	1.300000	1.300000	0.743492	0.743492	0.743492
0.743492	0.743492	0.743492	0.743492	0.743492	0.743492
0.743492	0.743492				

TOTAL PRESSURE ←*Dimensionless total pressure output.*

3.541104	3.541104	3.541104	3.541104	3.541104	3.541104
3.541104	3.541104	3.541104	1.156761	1.156761	1.156761
1.156761	1.156761	1.156761	1.156761	1.156761	1.156761
1.156761	1.156761				

```
FULLY DEVELOPED APPROXIMATION
APPROXIMATE WALL FRICTION=  0.0000000000000000E+00
APPROXIMATE WALL HEAT TRANSFER=  0.0000000000000000E+00
```

←*Wall skin friction and heat transfer (skin friction calculation not currently implemented).*

```
X LOCATION=  4.1666666666666666E-03
GRID POINT I=          1
LOCAL TURBULENT REYNOLDS NUMBER
  61144.04115928361

Y LOCATION
  0.000000   0.052083   0.104167   0.156250   0.208333   0.260417
  0.312500   0.364583   0.416663   0.416671   0.474995   0.533323
     .
     .
     .
```

←*Second station for flowfield output.*

```
X LOCATION=   4.166666666666668
GRID POINT I=          5
LOCAL TURBULENT REYNOLDS NUMBER
  38.06713468929672
```

←*Exit station for flowfield output.*

```
Y LOCATION
  0.000000   0.052083   0.104167   0.156250   0.208333   0.260417
  0.312500   0.364583   0.416663   0.416671   0.470000   0.523333
  0.576667   0.630000   0.683333   0.736667   0.790000   0.843333
  0.896667   0.950000
```

←*Cross-stream locations at exit plane.*

```
VELOCITY/UAVE
  1.169308   1.160481   1.126406   0.981123   0.972947   0.962365
  0.949366   0.933986   0.916338   0.916335   0.896153   0.874236
  0.851192   0.827836   0.805177   0.784362   0.766581   0.752946
  0.744368   0.741439
```

←*Exit dimensionless velocity profile.*

```
PRESSURE/PAVE
  1.392018   1.400658   1.441111   1.975009   1.932397   1.880620
  1.821739   1.758060   1.692010   1.692000   1.624415   1.559276
  1.498706   1.444418   1.397660   1.359203   1.329399   1.308283
  1.295720   1.291555
```

←*Exit dimensionless static pressure profile.*

```
MACH NUMBER
  1.101101   1.091202   1.053088   0.895219   0.888777   0.880450
  0.870236   0.858169   0.844347   0.844345   0.828563   0.811452
  0.793481   0.775282   0.757633   0.741418   0.727560   0.716928
  0.710234   0.707948
```

←*Exit Mach number profile.* ←*Note mixed supersonic/ subsonic exit profile.*

```
TOTAL PRESSURE
  2.976212   2.958229   2.905335   3.323098   3.228915   3.114501
  2.984419   2.843748   2.697814   2.697792   2.548381   2.404198
  2.269845   2.149040   2.044527   1.958090   1.890679   1.842622
  1.813887   1.804332
```

←*Exit dimensionless total pressure profile.*

The output file yprmw.out is printed below. This file contains cross-stream profile data at a location specified in the RLPRNT variable, in the input file zrdmix.in. For this case, this data was computed at

X=0.139, which is just downstream of the mixing plane. It is evident that the two flows have not had a chance to mix much at this location.

Cross-stream Profile Data at X/h(0)= 0.1388750000000000

Y	U/Uave	Mach	U Diff	Mom. Flux *(where Mom. Flux. $G=\rho u^2+p$)*
0.0000	1.3485	1.3062	1.0082	1.6436
0.0521	1.3485	1.3062	1.0082	1.6436
0.1042	1.3485	1.3062	1.0082	1.6436
0.1562	1.3485	1.3062	1.0081	1.6435
0.2083	1.3481	1.3057	1.0074	1.6436
0.2604	1.3463	1.3036	1.0044	1.6269
0.3125	1.3400	1.2963	0.9936	1.6025
0.3646	1.3130	1.2661	0.9479	1.4610
0.4167	1.0169	0.9523	0.4453	1.0649
0.4167	1.0136	0.9497	0.4398	1.0538
0.4737	0.7799	0.7652	0.0432	0.5757
0.5308	0.7677	0.7555	0.0225	0.5539
0.5879	0.7616	0.7507	0.0120	0.5455
0.6450	0.7599	0.7493	0.0092	0.5435
0.7021	0.7596	0.7491	0.0088	0.5432
0.7591	0.7596	0.7491	0.0087	0.5432
0.8162	0.7596	0.7491	0.0087	0.5432
0.8733	0.7596	0.7491	0.0087	0.5432
0.9304	0.7596	0.7491	0.0087	0.5432
0.9875	0.7596	0.7491	0.0087	0.5432

The Mach number profile at the exit of this nozzle is plotted in Figure 17. Note the combination of supersonic and subsonic flow at the nozzle exit.

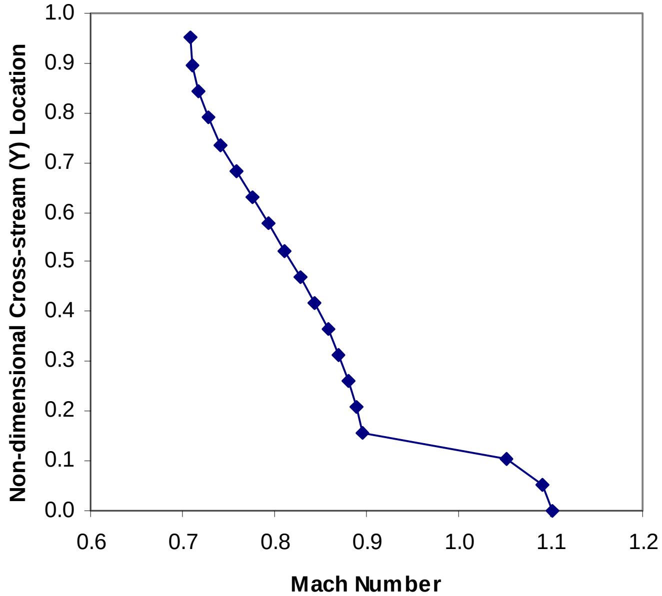


FIGURE 17. Exit Mach number profile for Supersonic/Subsonic Ejector example case.

(c) Supersonic Ejector Problem with Fabri Choke

The third example problem is a supersonic ejector nozzle, i.e., an ejector with fully supersonic exit conditions. The input conditions for this nozzle include a supersonic primary and a subsonic secondary. The secondary goes through an aerodynamic, or Fabri, choke in the mixing duct. As in the previous example case, changes were made to the total conditions and the primary Mach number in the input file flocond.in to effect the desired changes in the flowfield. In addition, control parameters in the file control.in that are required for a supersonic case with Fabri choke were changed. Finally, unlike the previous two subsonic ejector problems, this supersonic problem does use the expnd.in file. The expand.in file is reprinted below, though its contents are unchanged from the previous two examples. Files hwall.in and zrdmix.in remain unchanged.

File: control.in

```
&cntrl
   icnvl=0,        ←Compute performance and mixing solutions.
   ieject=1,       ←Ejector flow; i.e. compute secondary conditions.
   ist=1,          ←Supersonic exit condition.
   ifab=1,         ←Fabri choke solution.
   ispm=0,         ←Direct solution (no inlet stream static pressure match).
   iprnt=2,        ←Streamwise print control.
   ipw=1,          ←Cross-stream printer control.
   nmax=6,         ←Max. number of terms used in singularity solution.
&end
```

File: expnd.in

```
&exd               ←expnd.in file is used for this supersonic model.
```

```
   rm1s=1.8,            ←Initial guess of expanded primary stream Mach number.
   rm2s=0.8,            ←Initial guess of expanded secondary stream Mach number.
   dxe=.1,              ←Jacobian permutation for Broyden solver, approximately 0.1.
   relx=1.,             ←Relaxation constant (normally not used, set equal to 1.0).
   errm=1.d-6,          ←Maximum error in expand routines.
   nmx=500,             ←Maximum number of iterations in Broyden solver (expand solver).
   intt=100,            ←Number of intervals chosen to search for static pressure constrained
&end                       expansion problem.
```

File: flocond.in

```
&floc                   ←This file contains mixing plane information.
   p01d=8467.2,         ←Primary stream total pressure in lb/ft^2.
   p02d=2116.8,         ←Secondary stream total pressure in lb/ft^2.
   t01d=1037.38,        ←Primary stream total temperature in deg. R.
   t02d=518.69,         ←Secondary stream total temperature in deg. R.
   rm1=1.50,            ←Supersonic primary stream Mach number.
   rm2=0.4,             ←Initial guess of secondary stream Mach number.
   a1d=6.00,            ←Primary stream cross-sectional area in ft^2.
   a2d=8.40,            ←Secondary stream cross-sectional area in ft^2.
   a3d=13.68,           ←Exit plane cross-sectional area in ft^2.
   rg=1718.,            ←Air ideal gas constant (ft lb)/(slug deg. R).
   gam=1.4,             ←Specific heat ratio.
   pinf=2116.8,         ←Ambient static pressure.
   rec1=1.0,            ←Primary stream inlet recovery.
   rec2=0.98,           ←Secondary stream inlet recovery.
&end
```

The main output file, ejectd.out, for this supersonic ejector example is given below. This output file includes information specific to the supersonic and Fabri choke solutions. Comments appear in italics, as above. Note that there are two locations given for the aerodynamic choke; the "AXI" solution is for a nozzle with an axisymmetric cross-section of equivalent cross-sectional area as this two-dimensional model. Since the method does not perform three-dimensional analysis, however, this is of limited value. The solution for the Fabri choke location that will be of greater interest to the user will be that labeled as "2D". To save space, many of the station profile data has been excluded; data just after the Fabri choke is presented, however.

File ejectd.out:

```
*****************************************************

 ELEMENTARY INTEGRAL (C.V.) MIXING ANALYSIS
 VARIABLE AREA EXTENSIONS
 CODE AND ANALYSIS, LAWRENCE J. DE CHANT

 *****************************************************

 *****************************************************

 SUPERSONIC SOLUTION                        ←Supersonic solution.

 *****************************************************


 CRITICAL BACK PRESSURE INLET VALUES     ←Input values to critical back pressure calculation.
```

RM1S=   1.969857447460124   ←*Primary stream Mach number at choke location.*
RM2= 0.4716765315477534   ←*Secondary stream Mach number at choke location.*

A1SA1=   1.399364918191697   ←*Primary area at choke loc./Primary input area.*
A2SA2= 0.7152666477276737   ←*Sec. area at choke location/Sec. Input area.*
AREA TEST (A1S+A2S)/(A1+A2)=   1.000307593754350   ←*Test parameter.*

CRITICAL BACK PRESSURE COMPUTATION   ←*Computation of critical exit pressures.*

CRITICAL SECONDARY MACH NUMBER AND BACK PRESSURE
RM2CR=   1.004807925100409   ←*Computed sec. Mach number at choke location.*
PCRIT/P01= 0.2567272344150019   ←*Computed critical exit pressure.*

ACTUAL PRESSURE RATIO
PINF/P01= 0.2500000000000000   ←*Actual exit pressure; actual < critical implies supersonic exit solution is well posed.*
CRITICAL SECONDARY INLET VALUES   ←*Associated critical exit condition values.*
P2S/P1S= 0.4724760182045302   ←*Secondary static press./Primary static press.*
T2S/T1S= 0.6031976330526450   ←*Secondary static temp./Primary static temp.*
RMD2S/RMD1S= 0.4080729037864240   ←*Sec. mass flow rate/Primary mass flow rate.*
RM2S/RM1S= 0.6698719500669393   ←*Secondary Mach /Primary Mach.*

MIXED FLOW CONDITIONS AT CRITICAL   ←*Mixed flow conditions computed using*
INTEGRAL SOLUTIONS   *critical secondary Mach number (RM2CR).*

SUBSONIC MACH= 0.6425960106450168   ←*Exit plane ideally mixed Mach number. Both*
SUPERSONIC MACH=   1.776962582242195   *subsonic and supersonic solutions are meaningful.*
SUB PRESSURE=   3558.405183601888   ←*Exit plane ideally mixed static pressure.*
SUP PRESSURE=   1048.214671008546

SUB VELOCITY=   943.4257128079872   ←*Exit plane ideally mixed velocity.*
SUP VELOCITY=   2044.219111180626

SUB TEMPERATURE=   819.3887328683566   ←*Exit plane ideally mixed static temperature.*
SUP TEMPERATURE=   543.7010539433203

SUB DENSITY= 2.4170918766256303E-03   ←*Exit plane ideally mixed density.*
SUP DENSITY= 1.1155098854891980E-03

SUBSONIC TOTAL PRESSURE=   4697.574948334535   ←*Exit plane ideally mixed total pressure.*
SUPERSONIC TOTAL PRESSURE=   5814.640901375458

MASS CONSERVATION RESIDUALS   ←*Solution conservation values; should*
SUPERSONIC RESMP= -5.6943380729361357E-17   *be approximately zero.*
SUBSONIC RESMB= 1.7083014218808408E-16

ENERGY CONSERVATION RESIDUALS
SUPERSONIC RESEP= -9.8601176849997337E-17
SUBSONIC RESEB= 3.2867058949999108E-17

END OF CRITICAL BACK PRESSURE COMPUTATION   ←*Critical exit solution complete.*

EJECTOR SOLUTION ←*Beginning of ejector computations.*

FABRI CHOKE ←*Aerodynamic choke analysis.*

Primary stream quantities at mixing plane.

P1D= 2306.491244471154 ←*Static pressure (lb/ft^2).*
T1D= 715.4344827586208 ←*Static temperature (deg. R).*
U1D= 1967.667855697406 ←*Velocity (ft/s).*
RM1= 1.500000000000000 ←*Mach number.*
RH1D= 1.8765441310693207E-03 ←*Density (slug/ft^3).*
RMD1D= 22.15449339901633 ←*Mass flow rate (slug/s).*
P01D= 8467.200000000001 ←*Total pressure (lb/ft^2).*
T01D= 1037.380000000000 ←*Total temperature (deg. R).*

Secondary stream quantities at mixing plane (computed). (Similar variable definitions as for primary stream above, but for secondary stream. Secondary Mach number is initial guess.)

P2D= 1781.281396574101
T2D= 496.5936912227642
U2D= 515.4902611641064
RM2= 0.4716765315477534
RH2D= 2.0878926949541368E-03
RMD2D= 9.040822145078119
P02D= 2074.464000000000
T02D= 518.6900000000001

SUBSONIC MACH= 0.6889956819441811 ←*Fully mixed exit conditions. For this problem, both subsonic and supersonic values have meaning.*
SUPERSONIC MACH= 1.606393498139224

SUB PRESSURE= 3300.002508233145 ←*Exit plane ideally mixed static pressure.*
SUP PRESSURE= 1202.847761284349

SUB VELOCITY= 999.8544284827011 ←*Exit plane ideally mixed velocity.*
SUP VELOCITY= 1919.514205531843

SUB TEMPERATURE= 810.1395702869604 ←*Exit plane ideally mixed static temperature.*
SUP TEMPERATURE= 585.0911227987858

SUB DENSITY= 2.2806913270956926E-03 ←*Exit plane ideally mixed density.*
SUP DENSITY= 1.1879877298260962E-03

SUBSONIC TOTAL PRESSURE= 4532.988047846526 ←*Exit plane ideally mixed total pressure.*
SUPERSONIC TOTAL PRESSURE= 5161.288619871688
PRIMARY INLET RECOVERY= 1.000000000000000 ←*Primary and secondary inlet recoveries: input in flocond.in.*
SECONDARY INLET RECOVEY= 0.9800000000000000

NPR= 4.000000000000000 ←*Primary stream nozzle pressure ratio.*

PUMPING RATIO W2/W1= 0.4080807438133311 ←*Entrainment ratio w_2/w_1.*

CORRECTED PUMPING RATION W2/W1*(T02/T01)**.5 ←*Temperature corrected entrainment.*
W2/W1 CORR.= 0.2885566612220567

DIM. SHROUD LENGTH 4.166666666666667 ←*Dimensionless shroud length.*

SECONDARY TO TOTAL MASS FLOW W2/(W1+W2)= 0.2898134539558978	←*Mass flow ratio.*
P02/P01= 0.2450000000000000	←*Total pressure ratio between secondary and primary.*
SUBSONIC CFG= 1.058690571130366 SUPERSONIC CFG= 1.058690571130366	←*Gross thrust coefficient (does not include ram drag or divergence drag; includes expansion loss/thrust).*
GEOMETRY PRIMARY AREA= 6.000000000000000 SECONDARY AREA= 8.400000000000000 NET INLET ARE= 14.40000000000000 EXIT AREA= 13.68000000000000	←*Dimensional geometry (from input).*
MASS CONSERVATION RESIDUALS SUPERSONIC RESMP= -5.6943063675357843E-17	←*Solution conservation values; should be approximately zero.*
ENERGY CONSERVATION RESIDUALS SUPERSONIC RESEP= 1.3146780777676309E-16	
VARIABLE AREA MOMENTUM RESIDUAL SUPERSONIC RESMOMP= 0.0000000000000000E+00	
SUBSONIC ENTROPY GENERATION S/R= 11.61657570887090	
SUPERSONIC ENTROPY GENERATION S/R= 7.567269471949214	
SUPERSONIC STEADY SOLUTION	←*Supersonic solution.*
PO2/PO1= 0.2450000000000000 T02/T01= 1.000000000000000 A2/A1= 1.400000000000000 GAMMA= 1.400000000000000	←*Echoed input value ratios.*
RM2= 0.4716765315477534 RM2MAX= 0.6445462801430819	←*Secondary Mach number values used in search for critical area ratio.*
SEARCH FOR SOLUTION	←*Computations to estimate aerodynamic choke location.*
SECANT SOLUTION METHOD RM2S= 0.5520291073515466 RM1S= 1.711268633215997 RM1= 1.500000000000000 RM2= 0.4716765315477534	←*Values used in secant (Broyden) method solution.*
P2P1= 0.7722905520859779 T2T1= 1.388229679139771 U2U1= 3.746947890030977 RO2RO1= 0.5563132410225767	
CRITICAL BACK PRESSURE INLET VALUES RM1S= 1.711268633215997 RM2= 0.4716765315477534	←*Values used in computation of critical back pressure.*

A1SA1= 1.146363464214045
A2SA2= 0.7152666477276737

ESTIMATED AERODYNAMIC THROAT--FABRI CHOKE

XC AXI (xc/(2.*hys))= 1.728323559472122 ←*Estimated choke location for an axi nozzle.*
XC 2D (xc/(2.*hys))= 1.945470834516748 ←*Aerodynamic choke location/(2. * primary nozzle radius).*

PARABOLIC MARCHING CODE ←*Mixing/profile portion of output.*
STREAMWISE CRANK-NICOLSON, DX**2
CROSS-STREAM COMPACT, KRIESS DY**4
CONSERVATIVE FLUX, PRIMITIVE VARIABLE DECODE

CODE AND ANALYSIS: LAWRENCE J. DE CHANT; TEXAS A&M

AVERAGE VALUES ←*Area averaged quantities.*

RMAV= 0.9001446434028562 ←*Average Mach number.*
UAVE= 1120.564258886315 ←*Average velocity.*
GAVE= 5351.031353281856 ←*Average momentum flux.*
TAVE= 587.7773543627045 ←*Average temperature.*
ROAVE= 1.9998307933354635E-03 ←*Average density.*
PAVE= 2000.118833197873 ←*Average static pressure.*
RUAVE= 2.166341357228781 ←*Average specific mass flow rate.*
RUHAVE= 11554986.84482097 ←*Term from energy equation.*
PTOAVE= 4738.104000000000 ←*Average total pressure.*
PT0AVE/PAVE= 2.368911247350500 ←*Ratio of ave. total to static pressures.*
T0AVE= 734.8108333333334 ←*Average total temperature.*

GEOMETRY ←*Non-dimensionalized geometry variables.*
RL= 4.166666666666667 ←*Mixing length/h(0).*
HY/EPS2= 1.000000000000000 ←*Test variable, always equal to 1.0.*
EPS**.5= 1.5896701343325430E-02 ←*Test variable.*
DX0C= 0.8333333333333334 ←*Streamwise step size.*

DIMENSIONLESS INLET QUANTITIES ←*Non-dimensionalized inlet quantities.*

CONSERVATIVE VALUES ←*Conservative variables used in parabolic mixing flow analysis.*
G10= 1.788802575167999
G20= 0.4365695891657150
GC10= 2.076727391763005
GC20= 0.2309090058835678
RU10= 1.704447710505845
RU20= 0.4968230639243962
RUH10= 1.993288643801424
RUH20= 0.2905081115704112

PRIMITIVE INLET VARIABLES ←*Non-dimensionalized input quantities at mixing plane.*
RM1= 1.500000000000000 ←*Primary Mach number.*
RM2= 0.4716765315477534 ←*Secondary Mach number.*
U1= 1.755961641729493 ←*Primary velocity/Average velocity.*
U2= 0.4600273987646476 ←*Secondary velocity/Average velocity.*
P1= 1.153177104374064 ←*Primary static pressure/Average static press.*
P2= 0.8905877825899546 ←*Secondary static press./Average static press.*
T1= 1.217186197202728 ←*Primary static temp./Average static temp.*
T2= 0.8448670019980510 ←*Secondary static temp./Average static temp.*

PTO1= 4.233348468831869 ←*Primary total pressure/Average static press.*
PT02= 1.037170374863808 ←*Secondary total pressure/Ave. static press.*
RHO1= 0.9383514531944394 ←*Primary density/Average density.*
RHO1= 1.044034676289686 ←*Secondary density/Average density.*

HSP= 0.4166666666666667 ←*Cross-stream grid information.: Splitter plate*
JSP= 9 *height ratio; grid point counter.*
LOWER STREAM GRID SPACING
DY10= 5.2083333333333336E-02 ←*Lower stream grid spacing.*
UPPER STREAM GRID SPACING
DY20= 5.8333333333333327E-02 ←*Upper stream grid spacing.*
JUMP DELTA= 7.6733603947176556E-06 ←*Thickness of splitter plate.*

X LOCATION= 0.0000000000000000E+00 ←*First station location for profile output.*
GRID POINT I= 0
LOCAL TURBULENT REYNOLDS NUMBER
0.0000000000000000E+00

Y LOCATION ←*Cross-stream location for output data.*

0.000000	0.052083	0.104167	0.156250	0.208333	0.260417
0.312500	0.364583	0.416663	0.416671	0.475000	0.533333
0.591667	0.650000	0.708333	0.766667	0.825000	0.883333
0.941667	1.000000				

VELOCITY/UAVE ←*Dimensionless velocity output.*

1.755962	1.755962	1.755962	1.755962	1.755962	1.755962
1.755962	1.755962	1.755962	0.460027	0.460027	0.460027
0.460027	0.460027	0.460027	0.460027	0.460027	0.460027
0.460027	0.460027				

PRESSURE/PAVE ←*Dimensionless static pressure output.*

1.153177	1.153177	1.153177	1.153177	1.153177	1.153177
1.153177	1.153177	1.153177	0.890588	0.890588	0.890588
0.890588	0.890588	0.890588	0.890588	0.890588	0.890588
0.890588	0.890588				

MACH NUMBER ←*Mach number output.*

1.500000	1.500000	1.500000	1.500000	1.500000	1.500000
1.500000	1.500000	1.500000	0.471677	0.471677	0.471677
0.471677	0.471677	0.471677	0.471677	0.471677	0.471677
0.471677	0.471677				

TOTAL PRESSURE ←*Dimensionless total pressure output.*

4.233348	4.233348	4.233348	4.233348	4.233348	4.233348
4.233348	4.233348	4.233348	1.037170	1.037170	1.037170
1.037170	1.037170	1.037170	1.037170	1.037170	1.037170
1.037170	1.037170				

FULLY DEVELOPED APPROXIMATION ←*Wall skin friction and heat transfer (skin*
APPROXIMATE WALL FRICTION= 0.0000000000000000E+00 *friction calculation not*
APPROXIMATE WALL HEAT TRANSFER= 0.0000000000000000E+00 *currently implemented.*

X LOCATION= 4.1666666666666666E-03 ←*Second station for flowfield output.*
GRID POINT I= 1
LOCAL TURBULENT REYNOLDS NUMBER
47762.47109045983

```
Y LOCATION
  0.000000   0.052083   0.104167   0.156250   0.208333   0.260417
  0.312500   0.364583   0.416663   0.416671   0.474995   0.533323
     .
     .
     .

X LOCATION=   3.126041666666667                    ←Station located just after Fabri choke;
GRID POINT I=          4                               notice the secondary has become
LOCAL TURBULENT REYNOLDS NUMBER                        supersonic.
  43.39419859523789

Y LOCATION                                         ←Cross-stream locations at this station.
  0.000000   0.052083   0.104167   0.156250   0.208333   0.260417
  0.312500   0.364583   0.416663   0.416671   0.471249   0.525831
  0.580413   0.634995   0.689577   0.744159   0.798741   0.853323
  0.907905   0.962488

VELOCITY/UAVE                                      ←Dimensionless velocity profile.
  1.763889   1.764055   1.764555   1.765399   1.766599   1.768167
  1.770109   1.772420   1.775073   1.775073   1.778160   1.781459
  1.784830   1.788105   1.791111   1.793700   1.795766   1.797253
  1.796240   1.796572

PRESSURE/PAVE                                      ←Dimensionless static pressure output.
  1.026594   1.018479   0.994377   0.955051   0.901831   0.836669
  0.762139   0.681347   0.597751   0.597738   0.510952   0.428695
  0.354071   0.289263   0.235447   0.192880   0.161126   0.139373
  0.129354   0.125155

MACH NUMBER                                        ←Mach number output.
  1.534372   1.536104   1.541394   1.550539   1.564046   1.582661
  1.607396   1.639569   1.680827   1.680834   1.735978   1.805814
  1.892807   1.998623   2.122792   2.260758   2.401761   2.527960
  2.610475   2.642760

TOTAL PRESSURE                                     ←Dimensionless total pressure output.
  3.961853   3.940484   3.877106   3.773974   3.635045   3.466161
  3.275121   3.071546   2.866520   2.866491   2.663090   2.485197
  2.346295   2.258479   2.231154   2.268168   2.362157   2.487112
  2.623301   2.667978


X LOCATION=   4.166666666666668                    ←Exit station for flowfield output.
GRID POINT I=          5
LOCAL TURBULENT REYNOLDS NUMBER
  37.99327306243726

Y LOCATION                                         ←Cross-stream locations at exit plane.
  0.000000   0.052083   0.104167   0.156250   0.208333   0.260417
  0.312500   0.364583   0.416663   0.416671   0.470000   0.523333
  0.576667   0.630000   0.683333   0.736667   0.790000   0.843333
  0.896667   0.950000

VELOCITY/UAVE                                      ←Exit dimensionless velocity profile.
  1.676170   1.676453   1.677307   1.678741   1.680771   1.683415
  1.686691   1.690610   1.695171   1.695171   1.700481   1.706374
  1.712731   1.719367   1.726014   1.732325   1.737889   1.742275
```

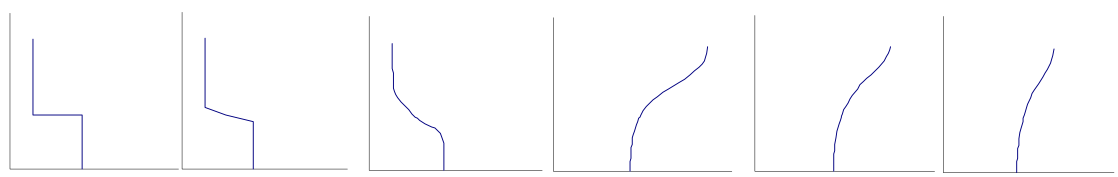
```
  1.745091   1.746063

PRESSURE/PAVE                                            ←Exit dimensionless static pressure profile.
  1.290312   1.281602   1.255809   1.213941   1.157624   1.089028
  1.010763   0.925743   0.837037   0.837024   0.745551   0.656494
  0.572628   0.496287   0.429324   0.373124   0.328649   0.296525
  0.277124   0.270637

MACH NUMBER                                              ←Exit Mach number profile.  Note fully
  1.445415   1.447052   1.452021   1.460495   1.472766   1.489257      supersonic exit flowfield.
  1.510525   1.537266   1.570306   1.570311   1.611638   1.661543
  1.720832   1.789741   1.867301   1.950438   2.033005   2.105387
  2.155813   2.174006

TOTAL PRESSURE                                           ←Exit dimensionless total pressure profile.
  4.379205   4.359820   4.302518   4.209834   4.085884   3.936221
  3.767614   3.587782   3.405093   3.405066   3.224071   3.058399
  2.916856   2.807205   2.735247   2.703178   2.707092   2.734547
  2.765251   2.778492
```

The Mach profile at each station along the flowfield is shown in Figure 18. The area of the duct where the secondary goes through the aerodynamic choke is evident. It can also be seen that the secondary stream accelerates to a higher Mach number than the primary stream downstream of the aerodynamic choke. This is a result of the aerochoke that occurs in a Fabri choke model. While this behavior is physically possible, it would probably not occur in an actual ejector due to the large amount of energy in the primary stream. The RLPRNT variable in the input file zrdmix.in could be modified to give profile data just prior to, or just after, the predicted location of the Fabri choke, and the program re-executed, if desired.



Mixing Plane Fabri Choke Nozzle Exit

FIGURE 18. Mach number profile along supersonic example nozzle length.

(d) Supersonic/subsonic Mixer Problem

The final example problem is a repeat of problem (b), Supersonic/subsonic Ejector Problem, that is run as a mixer and not an ejector. The difference between problem (b) and this current example case is that, where in problem (b) the entrainment was computed by the DREA method, in the current example the secondary entrainment is specified by the user input. For this case, then, DREA uses whatever secondary Mach number is given in the input file flocond.in and computes the resulting nozzle performance and flowfield. The exit pressure matching constraint is therefore not necessarily adhered to. As far as the input for this problem, the only change between example (b) and the current example case is in the input file control.in, which is printed below. The input file flocond.in from example problem (b) is repeated below for reference.

File control.in:

```
&cntrl
   icnvl=0,                ←Compute performance and mixing solutions.
   ieject=0,               ←Mixer problem; i.e., secondary flow is specified in flocond.in.
   ist=0,                  ←Subsonic exit condition.
   ifab=0,                 ←Back pressure constrained.
   ispm=0,                 ←Direct solution (no inlet stream static pressure match).
   iprnt=2,                ←Streamwise print control.
   ipw=1,                  ←Cross-stream printer control.
   nmax=6,                 ←Max. number of terms used in singularity solution.
&end
```

File flocond.in

```
&floc                      ←This file contains mixing plane information.
   p01d=6350.4,            ←Primary stream total pressure in lb/ft^2.
   p02d=2116.8,            ←Secondary stream total pressure in lb/ft^2.
   t01d=648.36,            ←Primary stream total temperature in deg. R.
   t02d=518.69,            ←Secondary stream total temperature in deg. R.
   rm1=1.30,               ←Primary stream Mach number.
   rm2=0.55,               ←Initial guess of secondary stream Mach number.
   a1d=6.00,               ←Primary stream cross-sectional area in ft^2.
   a2d=8.40,               ←Secondary stream cross-sectional area in ft^2.
   a3d=13.68,              ←Exit plane cross-sectional area in ft^2.
   rg=1718.,               ←Air ideal gas constant (ft lb)/(slug deg. R).
   gam=1.4,                ←Specific heat ratio.
   pinf=2116.8,            ←Ambient static pressure.
   rec1=1.0,               ←Primary stream inlet recovery.
   rec2=0.98,              ←Secondary stream inlet recovery.
&end
```

The output file, ejectd.out, for this example case is printed below. Note that the secondary Mach number has not been changed from the value specified in the input file flocond.in. This is different from example (b), where the secondary Mach number has been changed to produce the flow consistent with the subsonic exit pressure constraints.

File ejectd.out

```
*****************************************************

 ELEMENTARY INTEGRAL (C.V.) MIXING ANALYSIS
 VARIABLE AREA EXTENSIONS
 CODE AND ANALYSIS, LAWRENCE J. DE CHANT

 *****************************************************

 *****************************************************

 SUBSONIC SOLUTION                              ←Denotes a back pressure constrained
                                                      solution, though for a mixer case, the
 *****************************************************   pressure constraint may not be
                                                      adhered to.
```

MIXER SOLUTION ←*Mixer solution (entrainment input).*

Primary stream quantities at mixing plane.

P1D= 2291.947601406177 ←*Static pressure (lb/ft^2).*
T1D= 484.5739910313901 ←*Static temperature (deg. R).*
U1D= 1403.456641245643 ←*Velocity (ft/s).*
RM1= 1.300000000000000 ←*Mach number.*
RH1D= 2.7530964403726546E-03 ←*Density (slug/ft^3).*
RMD1D= 23.18310889938445 ←*Mass flow rate (slug/s).*
P01D= 6350.400000000000 ←*Total pressure (lb/ft^2).*
T01D= 648.3600000000000 ←*Total temperature (deg. R).*

Secondary stream quantities at mixing plane (input for mixing case). Similar variable definitions as for primary stream, but for secondary stream.

P2D= 1688.956824064305
T2D= 489.0994813767092
U2D= 596.5363165505487
RM2= 0.5500000000000000 ←*Note secondary Mach number is the same as what was input in flocond.in.*
RH2D= 2.0100098503281396E-03
RMD2D= 10.07196852769857
P02D= 2074.464000000000
T02D= 518.6900000000001

SUBSONIC MACH= 0.7568022117970568 ←*Exit plane ideally mixed conditions; note only the subsonic solutions are meaningful for this example. Ideally mixed Mach.*
SUPERSONIC MACH= 1.419357628579368

SUB PRESSURE= 2630.430789191709 ←*Exit plane ideally mixed static pressure.*
SUP PRESSURE= 1250.119371584499

SUB VELOCITY= 896.1320232076409 ←*Exit plane ideally mixed velocity.*
SUP VELOCITY= 1463.944870261443

SUB TEMPERATURE= 546.4868149209725 ←*Exit plane ideally mixed static temperature.*
SUP TEMPERATURE= 434.1579788711772

SUB DENSITY= 2.7126881414244516E-03 ←*Exit plane ideally mixed density.*
SUP DENSITY= 1.6605315964336382E-03

SUBSONIC TOTAL PRESSURE= 3844.812926500666 ←*Exit plane ideally mixed total pressure.*
SUPERSONIC TOTAL PRESSURE= 4088.476201183811
PRIMARY INLET RECOVERY= 1.000000000000000 ←*Primary and secondary inlet recovery; input in flocond.in.*
SECONDARY INLET RECOVEY= 0.9800000000000000

NPR= 3.000000000000000 ←*Primary stream nozzle pressure ratio.*

PUMPING RATIO W2/W1= 0.4344528842706681 ←*Entrainment ratio w_2/w_1. Note pumping for mixer is less than that for ejector (b).*

CORRECTED PUMPING RATION W2/W1*(T02/T01)**.5 ←*Temperature corrected entrainment.*
W2/W1 CORR.= 0.3885872220712001

DIM. SHROUD LENGTH 4.166666666666667 ←*Dimensionless shroud length.*
SECONDARY TO TOTAL MASS FLOW W2/(W1+W2)= 0.3028700970485768 ←*Mass flow ratio.*

P02/P01= 0.3266666666666667 ←*Total Pressure Ratio between secondary and* *primary.*

SUBSONIC CFG= 1.096054001537032 ←*Gross thrust coefficient. Note that C_{fg} for the*
SUPERSONIC CFG= 1.096054001537032 *mixer is less than that for the ejector (b).*

GEOMETRY
PRIMARY AREA= 6.000000000000000 ←*Dimensional geometry (from input).*
SECONDARY AREA= 8.400000000000000
NET INLET ARE= 14.40000000000000
EXIT AREA= 13.68000000000000

MASS CONSERVATION RESIDUALS ←*Solution conservation values; should*
SUBSONIC RESMB= -5.3416108962464202E-17 *be approximately zero.*

ENERGY CONSERVATION RESIDUALS
SUBSONIC RESEB= 8.9803444234768507E-17

VARIABLE AREA MOMENTUM RESIDUAL
SUBSONIC RESMOMB= -2.9103830456733704E-11

SUBSONIC ENTROPY GENERATION S/R= 6.011754841582841

SUPERSONIC ENTROPY GENERATION S/R= 3.968317275143167

SUBSONIC STEADY SOLUTION ←*Exit condition parameters and match.*
PINF= 2116.800000000000 ←*Ambient static pressure (input).*
P3B= 2630.430789191709 ←*Exit static pressure (computed).*
ERROR= 0.2426449306461210 ←*Note the back pressure is not constrained to match the exit pressure for the mixer.*

DEGREE OF MIXING IN PRESSURE CONSTRAINT ←*Estimation of pressure constraint matching.*
0.9888013516919762 *For mixer case, does not necessarily equal 1 since constraint is not enforced.*

TOTALLY UNMIXED (COMPARISON) ←*Test output.*
0.6305849916655908
PERCENT DIFFERENCE
36.22733316590108

XPN1=XCRIT/HW=nan ←*Test output.*

PARABOLIC MARCHING CODE ←*Mixing/profile portion of output.*
STREAMWISE CRANK-NICOLSON, DX**2
CROSS-STREAM COMPACT, KRIESS DY**4
CONSERVATIVE FLUX, PRIMITIVE VARIABLE DECODE

CODE AND ANALYSIS: LAWRENCE J. DE CHANT; TEXAS A&M

AVERAGE VALUES ←*Area averaged quantities.*

RMAV= 0.8625000000000002 ←*Average Mach number.*
UAVE= 932.7531185068381 ←*Average velocity.*
GAVE= 4616.924033754561 ←*Average momentum flux.*
TAVE= 487.2138603994929 ←*Average static temperature.*
ROAVE= 2.3196292628466877E-03 ←*Average density.*

```
PAVE=   1940.202981290085                  ←Average static pressure.
RUAVE=   2.309380376880766                 ←Average specific mass flow rate.
RUHAVE=   8457965.072066847                ←Term from energy equation.
PTOAVE=   3856.104000000000                ←Average total pressure.
PT0AVE/PAVE=   1.987474525699362           ←Ratio of ave. total to static pressures.
T0AVE=   572.7191666666668                 ←Average total temperature.

GEOMETRY                                   ←Non-dimensionalized geometry variables.
RL=   4.166666666666667                    ←Mixing length/h(0).
HY/EPS2=   1.000000000000000               ←Test variable, always equal to 1.0.
EPS**.5=  1.5783872738708977E-02           ←Test variable.
DX0C=  0.8333333333333334                  ←Streamwise step size.

DIMENSIONLESS INLET QUANTITIES             ←Non-dimensionalized inlet quantities.

CONSERVATIVE VALUES                        ←Conservative variables used in parabolic
G10=   1.670960052608765                        mixing flow analysis.
G20=  0.5207428195651679
GC10=   1.926792862569302
GC20=  0.3380050981647846
RU10=   1.673111767083416
RU20=  0.5192058806547031
RUH10=   1.780991943732814
RUH20=  0.4421486116194180

PRIMITIVE INLET VARIABLES          ←Non-dimensionalized input quantities at mixing plane.
RM1=   1.300000000000000                   ←Primary Mach number.
RM2=  0.5500000000000000                   ←Secondary Mach number (input for mixer).
U1=   1.504638916128539                    ←Primary velocity/Average velocity.
U2=  0.6395436313367581                    ←Secondary velocity/Average velocity.
P1=   1.181292691284398                    ←Primary static pressure/Average static press.
P2=  0.8705052205111445                    ←Secondary static press./Average static press.
T1=  0.9945817030616941                    ←Primary static temp./Average static temp.
T2=   1.003870212098790                    ←Secondary static temp./Average static temp.
PTO1=   3.273059603164549                  ←Primary total pressure/Average static press.
PT02=   1.069199470367086                  ←Secondary total pressure/Average static press.
RHO1=   1.186869162442799                  ←Primary density/Average density.
RHO1=  0.8665220268265723                  ←Secondary density/Average density.

HSP=  0.4166666666666667                   ←Cross-stream grid information: Splitter plate
JSP=           9                                height ratio; grid point counter.
LOWER STREAM GRID SPACING
DY10=  5.2083333333333336E-02              ←Lower stream grid spacing.
UPPER STREAM GRID SPACING
DY20=  5.8333333333333327E-02              ←Upper stream grid spacing.
JUMP DELTA=  7.6733603947176556E-06        ←Thickness of splitter plate.


X LOCATION=  0.0000000000000000E+00        ←First station location for profile output.
GRID POINT I=           0
LOCAL TURBULENT REYNOLDS NUMBER
  0.0000000000000000E+00

Y LOCATION                                 ←Cross-stream locations for output data.
   0.000000    0.052083    0.104167    0.156250    0.208333    0.260417
   0.312500    0.364583    0.416663    0.416671    0.475000    0.533333
   0.591667    0.650000    0.708333    0.766667    0.825000    0.883333
   0.941667    1.000000
```

```
VELOCITY/UAVE                                          ←Dimensionless velocity output.
  1.504639   1.504639   1.504639   1.504639   1.504639   1.504639
  1.504639   1.504639   1.504639   0.639544   0.639544   0.639544
  0.639544   0.639544   0.639544   0.639544   0.639544   0.639544
  0.639544   0.639544

PRESSURE/PAVE                                          ←Dimensionless static pressure output.
  1.181293   1.181293   1.181293   1.181293   1.181293   1.181293
  1.181293   1.181293   1.181293   0.870505   0.870505   0.870505
  0.870505   0.870505   0.870505   0.870505   0.870505   0.870505
  0.870505   0.870505

MACH NUMBER                                            ←Mach number output.
  1.300000   1.300000   1.300000   1.300000   1.300000   1.300000
  1.300000   1.300000   1.300000   0.550000   0.550000   0.550000
  0.550000   0.550000   0.550000   0.550000   0.550000   0.550000
  0.550000   0.550000

TOTAL PRESSURE                                         ←Dimensionless total pressure output.
  3.273060   3.273060   3.273060   3.273060   3.273060   3.273060
  3.273060   3.273060   3.273060   1.069199   1.069199   1.069199
  1.069199   1.069199   1.069199   1.069199   1.069199   1.069199
  1.069199   1.069199


FULLY DEVELOPED APPROXIMATION                            ←Wall skin friction and hat transfer (skin
APPROXIMATE WALL FRICTION=  0.0000000000000000E+00            friction calculation not
APPROXIMATE WALL HEAT TRANSFER=  0.0000000000000000E+00       currently implemented).


X LOCATION=  4.1666666666666666E-03                    ←Second station for flowfield output.
GRID POINT I=          1
LOCAL TURBULENT REYNOLDS NUMBER
  79130.20429795637

Y LOCATION
  0.000000   0.052083   0.104167   0.156250   0.208333   0.260417
  0.312500   0.364583   0.416663   0.416671   0.474995   0.533323
     .
     .
     .


X LOCATION=   4.166666666666668                        ←Exit station for flowfield output.
GRID POINT I=          5
LOCAL TURBULENT REYNOLDS NUMBER
  53.37174593684149

Y LOCATION                                             ←Cross-stream locations at exit plane.
  0.000000   0.052083   0.104167   0.156250   0.208333   0.260417
  0.312500   0.364583   0.416663   0.416671   0.470000   0.523333
  0.576667   0.630000   0.683333   0.736667   0.790000   0.843333
  0.896667   0.950000

VELOCITY/UAVE                                          ←Exit dimensionless velocity profile.
  1.313051   1.294669   1.106941   1.096576   1.081757   1.062231
  1.037751   1.008160   0.973485   0.973480   0.933054   0.888473
  0.841149   0.793075   0.746696   0.704633   0.669334   0.642780
```

0.626341	0.620781				

PRESSURE/PAVE ←*Exit dimensionless static pressure profile.*

1.354945	1.374765	1.947235	1.914306	1.870216	1.816998
1.757240	1.693983	1.630551	1.630542	1.568905	1.513897
1.468169	1.433352	1.409785	1.396404	1.390909	1.390245
1.391358	1.392004				

MACH NUMBER ←*Exit Mach number profile.*

1.098778	1.080156	0.896746	0.888535	0.876829	0.861461
0.842281	0.819215	0.792335	0.792331	0.761172	0.726998
0.690889	0.654332	0.619132	0.587220	0.560420	0.540231
0.527714	0.523477				

TOTAL PRESSURE ←*Exit dimensionless total pressure profile.*

2.888613	2.864359	3.281778	3.197852	3.085344	2.949246
2.795842	2.632407	2.466741	2.466717	2.302784	2.151959
2.020093	1.910905	1.825721	1.763535	1.721469	1.695596
1.681999	1.677815				

Figure 19 compares the exit Mach number profile for the mixer with that of the ejector (example (b)). The flowfield near the center of the duct is similar between the two problems. Near the duct wall, however, the effect of the different initial secondary Mach numbers for each case on the partially mixed flowfield can be seen. The solution arrived at by the ejector calculation, with exit pressure matching, gives a more uniformly mixed exit flowfield.

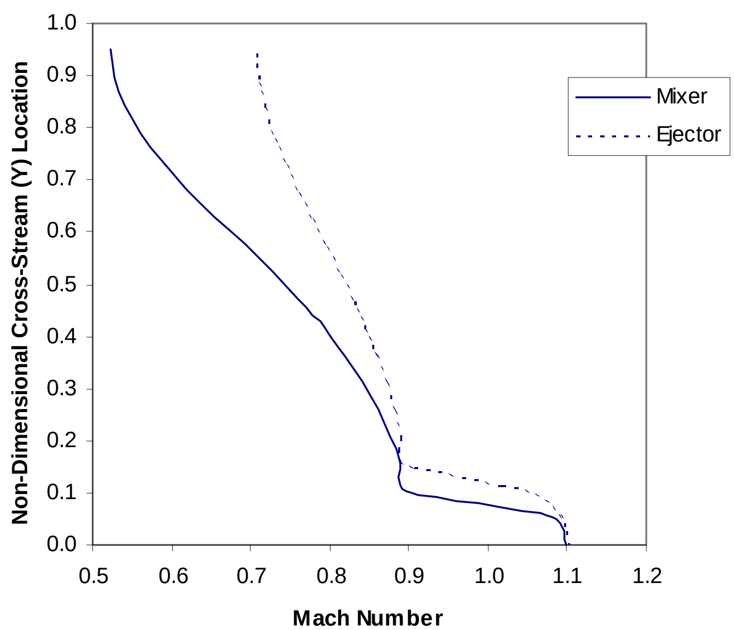


FIGURE 19. Exit Mach number profiles for Supersonic/Subsonic Mixer and Ejector.

Conclusion

This document provides background information necessary for the successful execution of the Differential Reduced Ejector/mixer Analysis (DREA) method. A brief description of the theoretical basis of the analysis method was discussed. A more detailed theoretical basis for this model is provided in reference 1. Detailed descriptions of the input parameters and the output files were provided. Four sample problems, three ejector nozzles and one mixer nozzle, were then presented, along with descriptions of the resulting output files. These problems were based on a fictional ejector nozzle design, and were intended solely for the purpose of demonstrating the use and operation of the DREA method. The user should be able to use these examples to become familiar with the program.

References

1. De Chant, L.J.: Combined Numerical/Analytical Perturbation Solutions of the Navier-Stokes Equations for Aerodynamic Ejector/Mixer Nozzle Flows. NASA CR-207406. April, 1998.
2. Fabri, J.; Siestrunck, R.: Supersonic air ejectors. *Advances in Applied Mechanics*. Vol V. Academic Press, New York. pp. 1-34. 1958.
3. Skebe, S. A.; Paterson, R. W.; Barber, T. J.: Experimental Investigation of Three-Dimensional Forced Mixer Lobe Flow Fields. AIAA Paper 88-3785. July, 1988.
4. Barber, T. J.; Paterson, R. W.; Skebe, S. A.: Turbofan Forced Mixer Lobe Flow Modeling. I-Experimental and Analytical Assessment. NASA Contractor Report 4147. 1988.
5. De Chant, L.J.; Nadell, S.B.; Seidel, J.A.: Subsonic Ejector Nozzle Limiting Flow Conditions. NASA Technical Memo, submitted November, 1997.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	April 1999	Technical Memorandum

4. TITLE AND SUBTITLE

A User's Guide for the Differential Reduced Ejector/Mixer Analsis "DREA" Program
Version 1.0

5. FUNDING NUMBERS

WU–537–09–00–00

6. AUTHOR(S)

Lawrence J. De Chant and Shari-Beth Nadell

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field
Cleveland, Ohio 44135–3191

8. PERFORMING ORGANIZATION REPORT NUMBER

E–11633

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM—1999-209073

11. SUPPLEMENTARY NOTES

Lawrence J. De Chant, Texas A&M University, College Station, Texas 77843 (work funded under NGT–51244); and Shari-Beth Nadell, NASA Glenn Research Center. Responsible person, Shari-Beth Nadell, organization code 2400, (216) 977–7035.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Categories: 07 and 64 Distribution: Nonstandard

This publication is available from the NASA Center for AeroSpace Information, (301) 621–0390.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

A system of analytical and numerical two-dimensional mixer/ejector nozzle models that require minimal empirical input has been developed and programmed for use in conceptual and preliminary design. This report contains a user's guide describing the operation of the computer code, DREA (Differential Reduced Ejector/mixer Analysis), that contains these mathematical models. This program is currently being adopted by the Propulsion Systems Analysis Office at the NASA Glenn Research Center. A brief summary of the DREA method is provided, followed by detailed descriptions of the program input and output files. Sample cases demonstrating the application of the program are presented.

14. SUBJECT TERMS

Design; Mixers; Mixing layers; Jet propulsion; Aeronautical engineering; Ejectors; System Analysis

15. NUMBER OF PAGES

51

16. PRICE CODE

A04

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	